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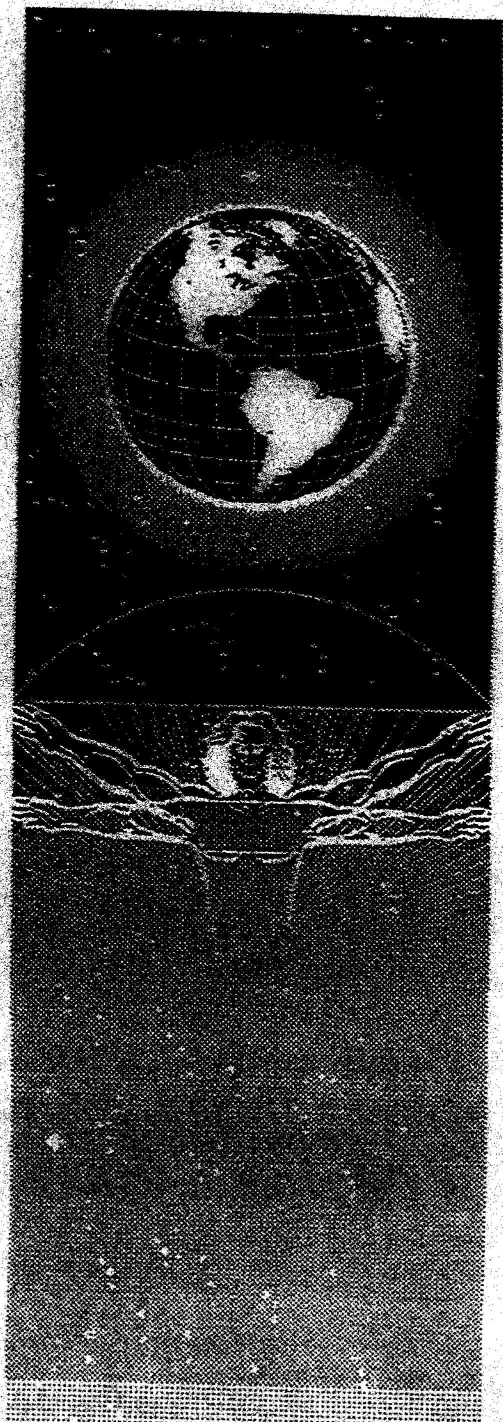

UNITED STATES AIR FORCE ARMSTRONG LABORATORY

HUMAN FACTORS EVALUATION OF THE AERIAL GUNNER SCANNER SIMULATOR

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This report has been reviewed and is approved for publication.

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13. ABSTRACT *(Maximum 200 words)*

This report describes a human factors evaluation of the Aerial Gunner Scanner Simulator (AGSS) that was installed at Kirtland Air Force Base, New Mexico, and is being operated by the 58th Special Operations Wing (SOW). A brief review of the literature concerning the levels of immersion associated with virtual reality (VR) is provided to help establish the nature of the VR environment provided by the AGSS and to give some context for the issues that accompany using VR for training. The evaluation was conducted using structured interviews with questions regarding the fidelity and/or ease of use of components from each of the AGSS's main systems, (i.e., trainee stations, instructor/operator stations , visual, and weapons) and its training capability for selected aerial gunner/scanner (AG/S) skills. Eleven experienced rotary-wing instructors volunteered to participate. The resulting ratings and comments were quite favorable, indicating that most of the AGSS components were acceptable. Two notable exceptions were the spaceball and object detection. Both areas were judged as being significantly poor and received low ratings. We report comments and discuss recommendations associated with the components that were judged acceptable or significantly poor. We conclude with a summary of the main findings and recommendations for improvement with their associated cost estimates.

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PREFACE

This report documents the results of a human factors evaluation of the Aerial Gunner Scanner Simulator which was conducted under Work Unit 1123-B3-01, Special Operations Forces (SOF) Aircrew Training and Mission Preparation Research. The Laboratory Work Unit Monitor is Dr. Robert T. Nullmeyer, Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division (AL/HRA). The work was supported by Work Unit 1123-B2-06, Aircrew Training Research Support, under Contract F41624-95-C-5011. The Laboratory Contractor Monitor is Mr. Daniel Mudd; the Laboratory Technical Monitor is Dr. Robert T. Nullmeyer.

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HUMAN FACTORS EVALUATION OF THE AERIAL GUNNER SCANNER SIMULATOR

INTRODUCTION

This report describes a human factors evaluation of the Aerial Gunner Scanner Simulator (AGSS) that was installed at Kirtland Air Force Base (KAFB), New Mexico and is being operated by the 58 Special Operations Wing (SOW). The evaluation was performed during the period January-August 1996, with survey data collected in March and April of the same year. The effort was conducted as part of a cooperative research effort between the 58 Training Support Squadron (TRSS) and the United States Air Force (USAF) Armstrong Laboratory, Human Resources Directorate, Aircrew Training Research Division (AL/HRA).

Declared ready for training (RFT) in March 1996, the AGSS was developed to provide a low cost, high fidelity virtual environment for training MH-53J Pave Low and M/HH-60G Pave Hawk flight engineers (FEs) and aerial gunner/scanners (AG/Ss). The AGSS is a state-of-the-art reconfigurable simulator that can train up to three crewmembers at a time. A dynamic virtual environment is presented through a head-tracked, full-color, helmet-mounted display (HMD) system that can support both daytime and night vision goggle (NVG)-night simulation. Using a three degree-of-freedom motion system, aural cueing, a powerful seven-channel image generator (IG), and digital computation system, the AGSS is capable of simulating air, sea, and terrain scenes; ground and airborne targets; and weapons effects, including tracer path and bullet impact (Reed, 1996).

Because the AGSS represents the first use of virtual reality (VR) for aircrew training at the 58 SOW, an assessment of the human factors aspects of the system was requested by the 58 TRSS. As one of the USAF Air Education and Training Command (AETC) training centers for excellence, the 58 SOW deemed it necessary to conduct a thorough evaluation of the AGSS from a human factors standpoint before incorporating the system into its impressive cadre of advanced weapon system trainers (WSTs).

The evaluation was designed to achieve three major objectives. First, the information collected during the evaluation was rapidly disseminated to key personnel within the 58 TRSS to ensure that high payoff, incremental design improvements to the AGSS could be made as soon as possible. Second, the effort sought to identify the skills most affected by use of the AGSS, thereby laying the foundations for a subsequent assessment of the effectiveness of the AGSS as a training device. Third, the research was designed to collect "lessons learned" information and other insights from subject-matter experts (SMEs) that could be used in the design, development, and implementation of other VR-based systems.

The remainder of the report is organized into four sections. We begin by providing some background on the AGSS. This includes a description of the training and design requirements for the system, a discussion of how VR technology is being applied to training and mission rehearsal (MR), a consideration of applying human factors analyses to VR technology, and a delineation of the scope of the human factors survey that we performed. In the next section we describe the methods used to conduct the survey, including a description of the AGSS, the subjects, the survey

instrument, data collection procedures, and the rationale behind the statistical methods used. The results section presents the overall findings of the survey, followed by separate analyses of the ratings and qualitative data. Finally, we summarize the major findings, offer some recommendations for AGSS design and use, and briefly introduce our research on AGSS training effectiveness and user acceptance.

Evolution of Training and Design Requirements for the AGSS

Since 1990, the 58 SOW has been vigorously developing a sophisticated set of simulation and electronic training technologies, as the USAF undergoes massive changes to become combat mission ready for the next century. Pursuing a path of innovative acquisition and an aggressive strategy for system development, along with an integrated approach toward academic instruction, flightline training, and simulation, the 58 SOW has acquired a "can-do" reputation for fielding sophisticated, reliable simulators in a short time period and incorporating these technologies into ongoing Mission Qualification (MQ) and combat mission training programs with minimal disruptions. As of 1996, the impressive capabilities available at the 58 SOW included eight high fidelity networked flight simulators; electronic classrooms for advanced academic instruction; a comprehensive database generation facility to construct photo-enhanced, geospecific visual databases for any location in the world; an integrated training and mission support system, employing computer-aided instruction (CAI); a cadre of database modelers and programmers; various hardware and software assets to support construction of photo-enhanced, geospecific databases; and functional links to multiple nodes on the Department of Defense's (DOD) Distributed Interactive Simulation (DIS) constructive battlefield simulation network.

As recently as 1990, the flight simulators were only beginning to come on line at KAFB. The first of these was the MH-53J WST—and its associated database generation system (DBGS) and mission planning system. The USAF wanted to assess the suitability of the MH-53J WST for supporting short suspense MR and training activities. An initial operational effectiveness evaluation was conducted in 1991 in the context of a joint Air Force-Army training exercise at White Sands, New Mexico (Nullmeyer, Bruce, Conquest, & Reed, 1992). Simulating a strike mission to recover critical equipment from a hostile third-world nation, the concept of operation called for five helicopter crews (3 MH-53Js, 2 MH-60Gs) to insert a 90-person Army team (assault and support) into the objective area during two consecutive nights. Throughout the assessment, AL/HRA scientists provided behavioral research support by directly observing the mission preparation process, interviewing selected mission participants, and administering formal, open-ended questionnaires following both MR and mission execution (Nullmeyer, Bruce, & Spiker, 1994).

The overall assessment of the MH-53J WST was positive, as evidenced by the high marks given the system by all the MH-53J and MH-60G pilots and FEs who were queried. Indeed, crew confidence in their mission plan was increased as a function of rehearsal in the WST (Nullmeyer, Spiker, & Reed, 1996).

Although the aircrews strongly endorsed the MR capability of the system, critiques by the AG/Ss contained some key points. Since the WST only simulates the cockpit for the two pilots and one FE, the AG/Ss did not rehearse in the device. The AG/Ss suggested that the *entire* crew

be included in the MR. They also indicated that the scanners need a visual capability of their own, and cited the need to communicate with the cockpit crew during the rehearsal to coordinate tactical activities and maintain situation awareness.

Based on this feedback, it was recommended that a simulation capability be developed that allows the AG/Ss to view the visual terrain database just as the pilots and FEs do, only from their vantage point at the rear and sides of the aircraft (Nullmeyer, et al., 1992). Not only would such a capability permit the training of crew-level tasks, as the entire crew would be present in the WST, it would aid development of key gunnery and scanning skills while reducing demands on the flightline to schedule sorties solely to accomplish AG/S-unique mission training events.

In parallel with the desire for full crew training, the 58 SOW explored developing a gunnery simulator to serve as an electronic part-task trainer (Reed, 1996). While developing the requirements for an AG/S training simulator, the 58 TRSS explored promising new technologies for incorporation into their formal specification. These included low-cost, small motion platforms; ruggedized, full-color HMDs; more accurate head-tracking systems; and smaller high fidelity IGs.

In May 1993, a contract was awarded to design the AGSS. At the outset, the AGSS was expected to provide full crew training and MR. Not only would the AGSS provide the first true MR capability for enlisted crewmembers, it would do so cost effectively by allowing squadron commanders to trade high value training flight hours for simulator time (Reed, 1996).

During the design phase, four key factors would alter the physical configuration of the device as well as shape the corresponding human factors evaluation. First, by using a modular architecture, the AGSS was to be reconfigurable to support either MH-53J or MH-60G training. This flexibility would not only increase the number and type of crewmembers to be trained, it also expanded the range of training events to be covered.

Second, the small size of the simulator device necessitated that the AGSS instructor/ operator station (IOS) not be mounted on the motion platform, but instead, be placed on the facility floor outside the MH-53J WST. This decision affects—and potentially limits—the ways that instructors may interact with their trainees. The resulting effects on both instructor and trainee must be captured in the human factors evaluation.

Third, to accommodate the heavy training schedule of the simulators at the 58 SOW, the AGSS needed to be designed for operation in both an independent (stand-alone) mode and integrated mode (networked with a cockpit simulator), enabling whole crew operations. The different requirements for operation, and the added complexities of using the AGSS while networked with other WSTs, must be reflected in a comprehensive human factors assessment.

Fourth, revolutionary advances in IG capability during the design phase created the exciting possibility of incorporating full VR into routine training. By scanning digital representations of the aircraft interior and displaying those on the AG/S's HMD, coupled with position-referenced aural cues and vibratory feedback from the guns, the AGSS has the potential to offer a truly immersive training environment. These novel aspects must also be explored in a human factors analysis of the AGSS. However, before further discussion of the general

methodological requirements of a comprehensive human factors evaluation, in the next subsection, we discuss some of the basic concepts of VR technology as applied to combat mission training and rehearsal.

VR Application Issues

From both a technological and societal perspective, VR has seen an unprecedented explosion in popularity, interest, and debate over the last few years. While multiple definitions abound, a common conception of VR is a type of interactive simulation that includes the user as a necessary component. Recently, however, it is has been noted (e.g., Thurman & Mattoon, 1991) that such conceptions are overly restrictive, since VR also encompasses the experience the user has in the artificial environment. Within DOD, the prevailing conception of VR is as an "interactive, usually computer-mediated, experience characterized by a suspension of (or inattention to) disbelief in the unreality of the experience" (DOD, 1994, p. 18).

In attempting to analyze the potential uses of VR in simulating a combat training environment, it should be noted that DOD Directive 5000.59 defines simulation as a "method for implementing a model over time (p. 4)." In turn, a model is viewed as a "physical, mathematical, or otherwise logical representation of a system, entity, phenomenon, or process (p. 4)." Accordingly, when assessing the effectiveness of a VR-based training device, it is important to address how *accurately* the simulation represents the objects of interest, how *realistically* the modeled objects behave over time, and how *efficiently* the modeled environment is delivered to the user.

Given the user's large role in the VR experience, it stands to reason that an assessment of the human factors aspects of the implementation is vital, as it will clearly influence how effective the simulation will be. In this regard, it is important to keep in mind that VR technology is not a single technology or medium, such as an HMD or a DataGlove™. Rather, it is an integrated human-computer system (Thurman & Mattoon, 1991). Consequently, when VR is incorporated into a training device, *all* aspects of the human-computer system—including input, interface, processing, and output—must be evaluated, both separately and in combination.

Among the various concepts used to explain VR, three are essential: virtual environment, immersion, and presence. A virtual environment is a simulated space in which a viewer or user may interact. Typically, a physical simulation of a vehicle, such as an aircraft or a tank, is the interface between the individual in the simulation and the virtual environment. For an individual to interact directly in a virtual environment, some or all of the following conditions must be met (Knerr, et al., 1993):

- free motion of the eyepoint in space;
- three-dimensional real-time interactive graphics, with stereopsis as needed;
- multiple senses beyond visual (e.g., audition, touch);
- direct manipulation of objects; and
- multiple interacting, mutually visible humans.

Considering these criteria, the AGSS and its associated IG-generated visual database certainly qualifies as providing a virtual environment for AG/S trainees.

Within the VR domain, immersion is achieved when one or more of the user's senses (typically vision and audition) are isolated from the surrounding environment and fed only information from a computer simulation (Pimentel & Teixeira, 1993). An HMD or large-dome display is typically required to achieve such immersion. However, true immersion is said to occur when the user interacts with the virtual environment as if it were his/her actual physical environment. By this definition, it would be difficult for an outside observer to attract the attention of a totally "immersed" user. This situation might pose some potential drawbacks in a training setting, where the instructor requires periodic, real-time contact with the trainee. Interestingly, there appear to be individual differences among users in their susceptibility to immersion, much as there is to hypnosis (Knerr, et al., 1993).

A related VR concept is presence, which is the subjective experience of being in one place when one is physically in another (Bailey & Witmer, 1994). In a sense, presence can be viewed as a weaker form of immersion, since the user's senses do not need to be fully engaged. Importantly, this may be a more realistic and practical goal for a VR-based training technology. In this regard, there is evidence to suggest that users can still experience presence while modifying the viewpoint in the virtual environment, thus improving their overall spatial knowledge of objects in the virtual world (Mowafy & Miller, 1993).

As a technology, there has been a rapid expansion of VR capabilities since the early 1980s. Depending on price and one's task area of interest, it is possible to distinguish among four levels of VR (DOD, 1994). Entry level VR includes a cathode ray tube (CRT) graphic display; desk top computer; and a two-dimensional input device, such as a mouse, trackball, or joystick. Expansion into a Level 2 or basic VR adds some basic interaction and display enhancements. These might include a stereographic viewer and a more capable input device. The latter might be either a DataGlove™ or a multidimensional (3- or 6-dimension) mouse or joystick.

Stepping up to Level 3 or advanced VR entails the addition of a rendering accelerator card for faster display of animated graphics and possibly a sound card for true 3-D audio output. As parallel processors have come down in price, it has become more feasible to render real-time imaging video over a larger display area. Such a capability adds realism to the visual presentation and typically enhances the user's interest and enjoyment of the experience. Moreover, including audio feedback has been shown to dramatically enrich the user's VR experience (Miner, 1994).

One reaches the highest level of VR (Level 4) by adding some type of immersive display system. At the present time, the choices are HMDs, multiple large project displays, or binocular omni-orientation monitors (BOOMs). A BOOM device has the viewer look through a stereoscopic display whose field of regard is swiveled around a fixed boom platform. In each case, it is typically assumed that the user will have an "immersive experience" if the display can provide at least 60° of horizontal field of view (FOV). An immersive system might also involve some form of haptic interaction mechanism so that the user can feel virtual objects.

Given the sophisticated computational and display capabilities associated with the AGSS, this system clearly satisfies all the criteria for a Level 4, the highest level of immersion for VR technology. While achieving immersion is a worthy goal from a technological standpoint, it remains to be seen whether that sophistication translates into improved user performance or increased training effectiveness.

Although there is now considerable commercial interest in VR, its application to combat mission training is still in its infancy. For example, the Army Research Institute (ARI) is exploring the use of VR technology to create virtual environments for training spatial knowledge with dismounted soldiers (Bailey & Witmer, 1994). Researchers are finding evidence that participants can learn to navigate through real-world places by training in a virtual environment, although such training is not as effective as walking through an actual building. On the other hand, the differences between VR and real-world navigation training in producing accurate spatial knowledge may dissipate with greater amounts of practice.

The Defense Advanced Research Projects Agency (DARPA) and the Army Test and Evaluation Command (TECOM) are conducting a joint project to determine the feasibility of using VR technology to train automobile drivers to achieve high levels of performance on an instrumented test track (Kuhl & Wargo, 1994). Initial transfer of training results are encouraging, and through use of virtual prototyping simulation, the investigators are exploring the applicability of VR to conduct tactical battlefield training in DIS-based exercises.

Not surprisingly, the USAF is sponsoring research to study the effectiveness of VR technology in training situation awareness among fighter pilots (Hettinger, Nelson, & Hass, 1994; Mowafy & Congdon, 1994). Researchers at AL/HRA are collecting data to identify those spatial knowledge tasks whose performance appears to be aided by training in a virtual world. Some of the areas where VR technology appears to hold promise involve providing pilots with multiple perspectives (i.e., inside the cockpit vs an outside or exocentric point of view) during an engagement, navigating through the environment in three-dimensions to estimate energy management performance, simultaneous comparison of flight trajectories flown by students and experts, and joint use of icons and audio to give students immediate feedback concerning performance in a simulated mission (Mowafy & Congdon, 1994).

While the potential for VR technology to positively impact combat mission training is quite real, there are nevertheless some problem areas that have been highlighted in past implementations. These problem areas must be resolved in any successful application and, accordingly, will be assessed in our human factors survey.

There have been numerous reports, mostly anecdotal, of problems experienced by HMD wearers in simulation settings. The most commonly reported problems include eye strain, blurred vision, headaches, and occasionally, debilitating "flash backs" that occur several hours after the simulation experience. In some cases, inadequate performance of the head-tracking mechanism causes significant transport delays, producing system lags that result in scene blurring as the user moves his/her gaze across the display. Other perceptual problems have been reported due to the insufficient display resolution in many present-day HMD image sources (e.g., liquid crystal displays or LCDs) for rendering detailed graphic scenes (DOD, 1994).

Another class of problems with VR technology entails user performance. For example, there are frequent reports of users becoming disoriented while navigating in virtual environments (e.g., Mowafy & Congdon, 1994). Since the user's bearing is variable in a virtual world, it is often difficult to maintain a consistent azimuthal relationship between one's self and significant objects (e.g., targets) in the environment. Consistent with this problem, there are many reports of users walking into objects, both virtual and real world, while navigating through VR environments (DOD, 1994).

Perhaps the largest potential problem concerns the apparently high incidence of simulator sickness observed in a number of previous VR implementations. As in any simulation setting, discrepancies between vection (perceived self-motion) and visual feedback from the VR simulation can cause discomfort, a feeling of nausea, or outright sickness among many subjects (Lane, Kennedy, & Jones, 1994). The percentage of VR users who experience some degree of sickness varies, with one study (Bailey & Witmer, 1994) excusing only 16% of their subjects due to illness, while Knerr et al. (1994) reported simulator sickness symptoms in **most** of their study participants.

The true incidence and extent of simulator sickness will no doubt vary as a function of many conditions. For example, there is some evidence to suggest that the amount of presence experienced in the VR setting is negatively related to the severity of simulator sickness reported for that environment (Knerr et al., 1994). Moreover, there are also data suggesting that simulator sickness may adversely affect performance, even for those participants who do not experience severe symptoms (Bailey & Witmer, 1994). Anecdotally, some believe that experiencing a VR simulation while on a motion base (as opposed to a fixed-base) will alleviate many simulator sickness problems (DOD, 1994). Whatever the mechanism(s), it is clear that definitive steps will need to be taken to reduce the incidence of simulator-induced illness before VR technology can be implemented as a training medium on a large scale.

Viewed in the long term, it is reasonable to expect that VR will prove effective for some training tasks and not for others. As such, VR will not be the "silver bullet" that revolutionizes the military's approach to training nor radically alters how training is conducted at the squadron level. Consequently, the job of the behavioral scientist is to identify the *characteristics* of the user's tasks whose performance are aided, hindered, or unaffected by VR so that the latter may be judiciously and cost-effectively applied to other weapon training systems (Lane et al., 1994). Such identification is the guiding focus of the human factors evaluation described in this report.

Human Factors Analysis of VR Technology

Human factors is a subdiscipline of psychology whose primary objective is to design machines and/or work environments that accommodate the limits of the human user (Wickens, 1984). As typically practiced, a human factors analysis will conceptualize the human-machine environment as a total *system* whose components and component relationships may then be examined in more detail. Figure 1 depicts the user-machine environment as typically conceived in a human factors analysis.

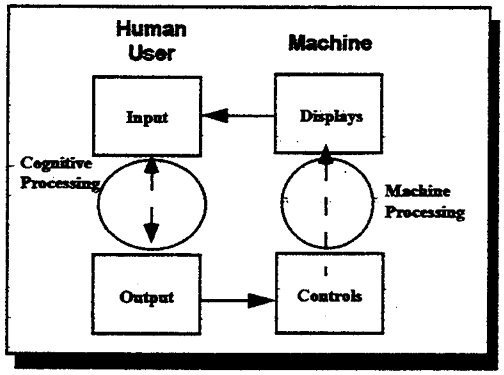

Figure 1. Typical Human Factors Conception of the User-Machine Relationship.

As seen in the figure, the limitations and capabilities of the human user can be studied at several points in the system. The user's abilities to make inputs to the machine should be considered. Depending on the application, the user might make inputs to the machine using components such as a keyboard, joystick, mouse, touch screen, or voice recognition system. Each of these in turn might involve interaction from the user using various parts of the body, such as fingers, arms, and vocal chords. The corresponding human capacities in such areas as strength, dexterity, speed, or stamina need to be reviewed to determine their suitability for the machine's control mechanisms (Van Cott & Warrick, 1972).

As machine inputs are processed, their results are displayed back to the user in some form. Display choices might be a CRT, HMD, large dome, and voice, to name just a few. Again, human limitations in the sensory domain of the display (vision, audition, touch) must be considered to ensure that the displayed information is sufficiently large, detectable, perceptible, legible, and so forth (Grether & Baker, 1972).

The circles in the middle of the figure encompass what is rapidly becoming the most critical area of human factors—information processing. Thus, regardless of the method of display or the medium of control, substantial processing will occur by both the human-user and the machine. Since the processing of both entities is hidden from direct observation, the challenges facing the human factors analyst are greatest here (Kantowitz & Sorkin, 1983). On the machine side, the focus will be to ensure that the system responds sufficiently soon after input so that the user does not experience any lag or delay that might degrade his/her performance. Responding to the user side, the goal is to design the system so that user's cognitive processing capacities (attention, short-term memory, long-term memory, etc.) are not overwhelmed.

With regard to understanding the impact of VR technology on these factors, thorough human factors analyses are essential when new VR devices are introduced into training programs, because limitations in the user-device interactions will undoubtedly establish upper limits on the device's training effectiveness. There are several key elements of a well-designed human factors study. First, the analysis should attempt to distinguish between problems resulting from limitations in the user's basic sensory-cognitive-motor capacities versus those arising from deficiencies in the machine. Such a distinction is necessary so that when problems in device use

are encountered, the proper solution(s) can be determined—modifying the device, providing additional training to the user, or both.

As applied to the AGSS as a VR device, the human factors analysis looks at the users' experiences of immersion, presence, and navigation through the virtual environment. It also addresses potential anthropometric (i.e., fit and feel) problems posed by wearing an HMD for extended periods of time. The analysis also looks for reported instances of simulator sickness and attempts to correlate those reports with the control-display conditions that were present at the time of symptom onset.

Second, a human factors analysis should utilize a sufficiently broad array of data collection methodologies so that all of the relevant aspects of human functionality are covered. That is, the analysis should examine the visual requirements of the user, as well as his/her auditory, cognitive, and haptic needs. Moreover, the analysis should include measures that distinguish between operability of the device (i.e., is it as easy to use as practically possible) versus its acceptance by the user (Wickens, 1984). We explicitly incorporated all of these features into our human factors analysis of the AGSS, except for acceptance. Although we recognize the importance of acceptance for the complete analysis of aircrew training devices, we only tangentially address this issue within our survey. As discussed below, it is a research issue we will investigate more explicitly and thoroughly in our subsequent AGSS research efforts.

In addition, a human factors analysis should survey a number of different users who have had experience with the system. It should include a mix of survey, interview, and observational measures to ensure that data on input, output, controls, displays, and processing deficiencies are identified. The analysis should include measures that tap into both the device's ease of use as well as its effectiveness in achieving the users' stated training objectives. Our analysis of the AGSS incorporates all of these features.

Scope of the Human Factors Survey

The Human Factors Survey Framework depicted in Figure 2 is designed to capture the logic underlying our presentation of human factors issues associated with the AGSS and its various components. In addition, the framework characterizes our thinking regarding ensuing research efforts related to the acceptance and training effectiveness of the AGSS. The topics explicitly covered by the present survey are included within the shaded box. The items outside of the box were not explicitly explored in this survey, but are nonetheless, relevant to the overall assessment of the AGSS as a training device. A description of the survey framework follows.

Moving from left to right, we start with the assumption that the device was built according to certain design specifications which met government standards since the device was approved as RFT in March 1996. As shown in the figure, these design specifications are applicable to each device component, i.e., helmet, trainee stations, IOS, weapons simulation, and visual system. (The specific design specifications for the AGSS are not described in this report. We do, however, provide a general description of the main systems of the AGSS in the Method Section.) Associated with each device component will be a host of human factors issues, represented in the Human Factors boxes to the right of each device component.

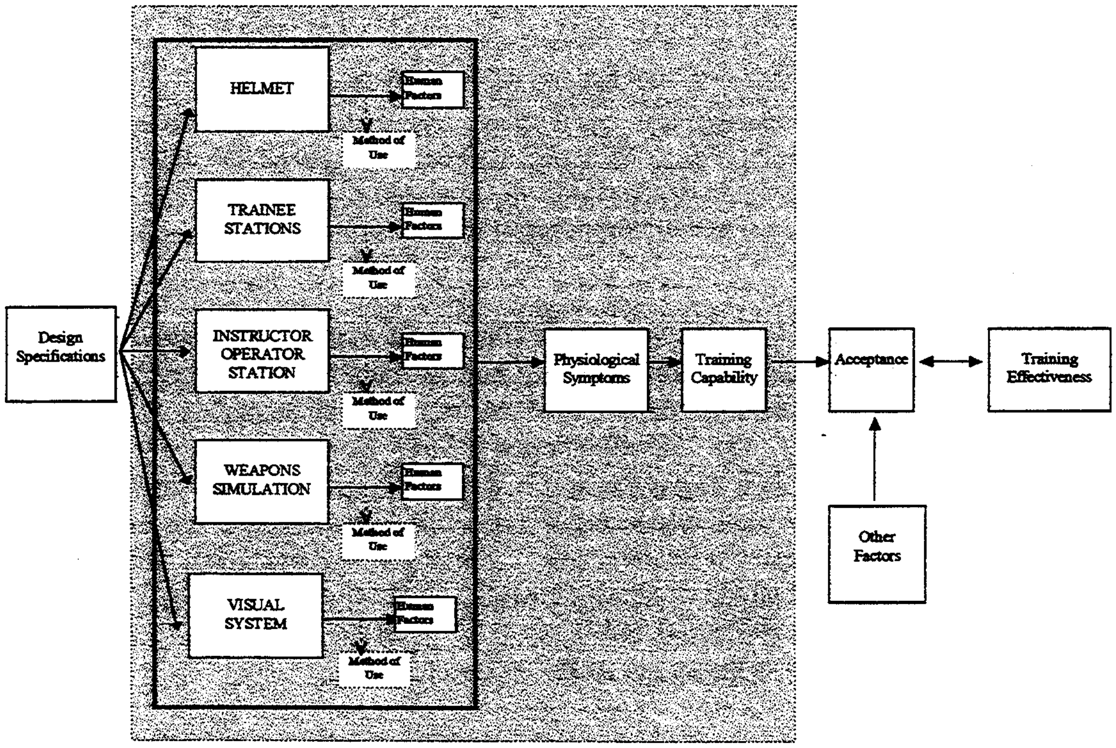

Figure 2. Human Factors Survey Framework.

Below each arrow is a dotted Method of Use box indicating that a component's use may affect certain human factors assessments. For example, the IOS may be judged as highly effective and "user friendly" when one student is being trained in an AGSS station, but this assessment may change dramatically if there are two or three students being trained simultaneously in the AGSS. Alternatively, the helmet may rarely be judged as problematic when the device is used for short durations, but rated much lower when it is used for longer time periods. The Method of Use box is dotted to indicate that these factors may or may not affect participants' human factors assessments. When describing the results for each device component, we will first discuss the significant human factors findings, and then where applicable, the effects due to different methods of use.

The survey also covers select overall device assessments, as represented by the two small solid boxes, Physiological Symptoms and Training Capability. We assessed the occurrence of any unusual physiological symptoms (e.g., dizziness, blurred vision, etc.) during or following the use of the AGSS. In addition, as a lead-in to a subsequent planned study of AGSS training, we also examined the overall training capability of the device by soliciting SME commentary on the capability of the AGSS to train selected AG/S skills.

The next box in Figure 2 is Acceptance, which includes both instructor and student acceptance of the AGSS, and the training it provides. Acceptance is an important contributor to the training effectiveness of this (or any) device, and in many ways reflects the sum of the previous components of the model. That is, human factors judgments of the various components,

the experience of unusual physiological symptoms, and its training capability will undoubtedly be summed and weighted in subjective ways by both AGSS students and instructors to influence their acceptance of the device. We also realize, as depicted in the box below Acceptance, that Other Factors (e.g., preconceptions about simulators, age, rumors about device-associated reductions in flying hours, etc.) will affect device acceptance. Acceptance lies outside of the large shaded dotted box because it is not explicitly addressed in this survey. However, some participants made direct references to acceptance in their comments, and we cite these reports where appropriate in the results section. We have included the Acceptance and Training Effectiveness boxes in our model as these are the next two research areas we will pursue after this survey. Training Effectiveness is shown to the far right since we expect that it will reflect all of the preceding factors. The bi-directional arrow connecting the Acceptance and Training Effectiveness boxes acknowledges the likelihood that these two items are highly interdependent.

The above description by no means exhausts all of the factors that might potentially be included in an analysis of the utility and design of the AGSS. It does, however, establish the dominance of human factors issues in determining the training effectiveness of the AGSS while also providing an effective context for understanding the survey results.

METHOD

AGSS System Description

The AGSS (see Figure 3) is a ground-based trainer designed to provide both basic skills and MR training to USAF AG/S and FE personnel. The AGSS is a reconfigurable (MH-53J and MH-60G) device with a three-degree-of-freedom (pitch, roll, and heave) motion base. The device simulates sound, recoil vibration, trajectory, and visual imagery for both the .50 caliber (cal) and 7.62 millimeter (mm) guns. Gun design mimics actual gun control, position, weight, feel, and operation. All ship, gun, and air sounds are heard by the trainees, including: engines, rotors, guns, landing gear, warnings, and airstream effects. The visual system provides both day and NVG night scenes including: outside view, inside cabin, gun barrel, fixed and moving targets, weapon effects, effects of hits or misses, and environmental conditions. The AGSS is designed to operate as a stand-alone trainer (AGSS only), an integrated trainer (AGSS with a host cockpit, either the MH-53J WST or the MH-60G WST), or networked (AGSS with a host and multiple training devices).

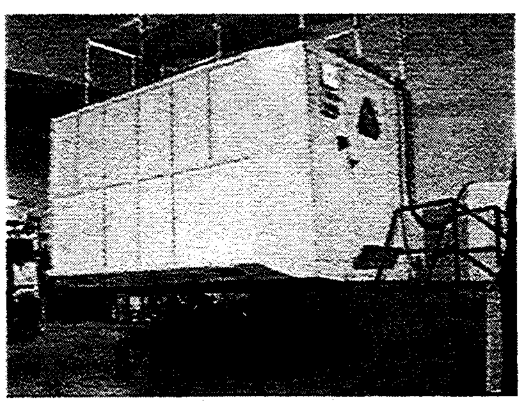

Figure 3. Outside View of the AGSS.

The main systems we examined in the survey are presented in Figure 4. Although this listing does not include all of the systems that comprise the AGSS, it does cover those of greatest interest to the end user, where the Trainee Station is central. In addition, systems not identified in the figure may be captured within the context of larger applicable systems (e.g., aural cues (gun sounds) within Weapons Simulation). With this schematic in mind, a brief description of each major AGSS system follows.

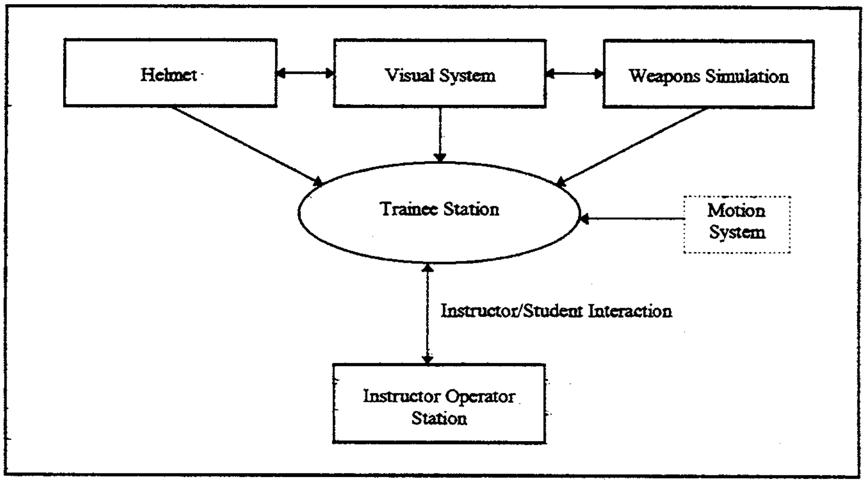

Figure 4. Main System Schematic of the AGSS.

Helmet

The AGSS is equipped with three helmets for the left, right, and tail positions. The helmet is a Kaiser Electro-Optics Sim Eye™ (see Figure 5). It is enclosed, lightweight (2 lbs), and fully adjustable with removable velcro pads of various sizes. Each helmet has a binocular HMD which is attached to the helmet using plastic screws. In addition, each helmet is equipped with a magnetic head-tracker system. The electronic and communication cables attach to the HMD and extend past the shoulders and lead up to the electronic interface unit (EIU) in the center of the AGSS. Each helmet also has headphones and a microphone.

Figure 5. Kaiser Electro-Optics Sim Eye™ AGSS Helmet.

Trainee Stations

As mentioned, up to three students can be trained simultaneously in the AGSS. Each trainee station provides a spatially and visually correct representation of the aircraft (either the MH-53J or the MH-60G, depending on the designated configuration). A 7.62 mm or a .50 cal weapon can be mounted in each station. The visual representation of the station is transferred through the IG and contains aircraft-specific texturing and details. All window frames and edges have the appropriate spatial relationship to the gunner. In addition, crew seats and harnesses are visually and functionally realistic.

Instructor Operator Station

Instructors are located outside the device at an IOS with six screens (see Figure 6): one for instructor input (lower left); one for information output (upper left); one for instructor viewpoint selection, either pilot's eye view, God's eye view, or Target Zoom (lower middle); and three that repeat each trainee's visual scene (i.e., Left Station, upper middle; Right Station, upper right; Tail Station, lower right). There are two positions at the IOS, each with a headset. The primary instructor position is located in front of the instructor input and output screens. From this position the instructor is capable of interacting with the students in the AGSS through the intercom. The second position is in front of the student repeater screens. The instructor or observer at this station can watch and listen to all of the training activities, but he/she cannot interact directly with the students in the AGSS through the intercom. The IOS also has a space ball—which enables the instructor to position targets, fly air-to-air models, and fly the AGSS when it is used for stand-alone training—a color printer, and a work table. Pre-programmed flight paths can be recorded and replayed for multiple practice sessions on the same flight path. Performance monitoring pages allow trainers to print out gunnery performance scores (e.g., number of hits, type of ammunition, etc.) for individual gunners as well as gunner crews.

Figure 6. AGSS Instructor Operator Station.

Weapons Simulation

The AGSS is capable of simulating sound, recoil, vibration, trajectory, and visual imagery for both the .50 cal and the 7.62 mm guns (see Figure 7). The AGSS duplicates all gun controls, positions, weight, feel, and operations of each gun. High fidelity airstream effects vary with airspeed and gun orientation. These airstream effects are provided through individual control loading mechanisms which support all three gun positions.

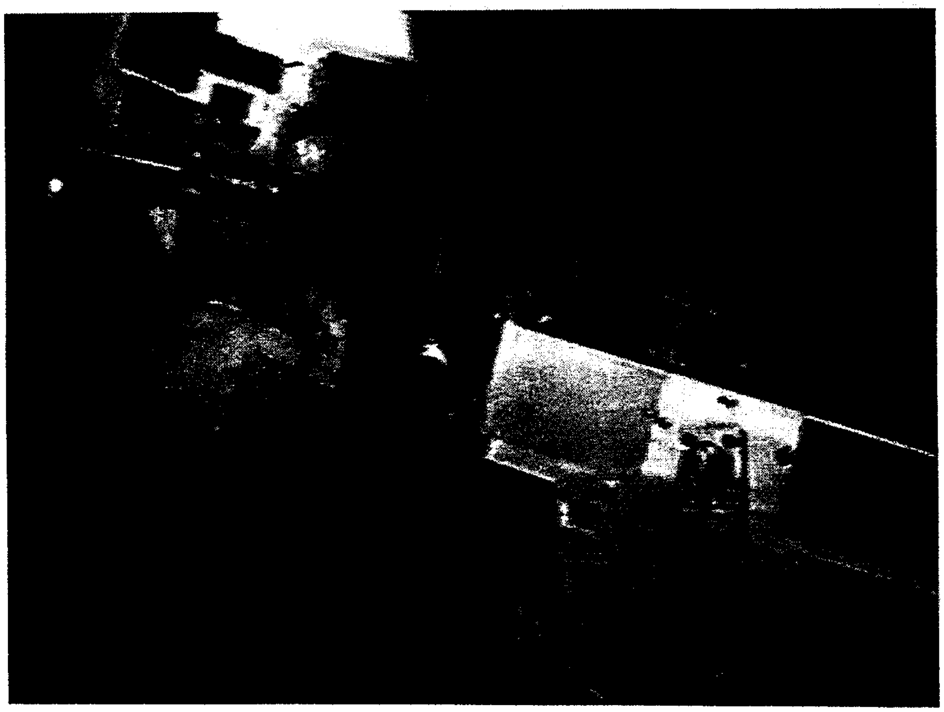

Figure 7. Left Aerial Gunner Station with 7.62 mm Weapon Mounted in the Window.

Visual System

The primary components of the visual system are: the HMD, the head-tracker system, and the IG. The HMDs are full-color and support a 60° by 40° FOV with 1028 by 1024 resolution. The head-tracker system has an eight-foot radius and provides head position and attitude information to the IG and host computer. There is one transmitter with a receiver on each of the three helmets. The SE 2000 IG is used when the AGSS is in stand-alone mode. When the AGSS is in network mode, other IGs available at the 58 TRSS, like Compuscene V, may be used. The IG provides photo-specific scenes to the HMDs. The visual simulation includes interior aircraft features (e.g., cabin, weapon barrels, etc.) and exterior aircraft features (e.g., rotors). Further, the out-of-the-window depiction includes: air, sea, terrain scenery, targets, and weapons effects, i.e., tracer path and bullet impact (Reed, 1996).

Subjects

Eleven experienced rotary-wing instructors volunteered to participate in this survey; five FEs and six AGs. Ten were crewmembers from the MH-53J weapon system and one was from the MH-60G. Seven were active duty USAF and four were Lockheed Martin instructors. All

survey participants had extensive instructor experience in their respective positions. In addition, every participant had some level of experience with the AGSS. A summary of the participants' AGSS and flying experience appears in Table 1.

Table 1. Summary of Survey Participants' AGSS and Flying Experience.

	Position					
	Flight Engineer (n=5)			Aerial Gunner (n=6)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
AGE	40	48	32	36	43	28
AGSSTOT	34.80	100.00	2.00	114.33	300.00	1.00
AGSSBOX	5.70	12.00	.50	19.33	50.00	1.00
COMBAT	226.80	433.00	.00	86.17	280.00	.00
FLYTIME	4520.00	6500.00	1800.00	1720.00	2500.00	720.00
FLYTLM	8.00	20.00	.00	19.17	40.00	.00
FLYTNVG	1420.00	2500.00	900.00	1141.67	2000.00	500.00

Note. AGSSTOT = estimated total number of hours experience with the AGSS, either during development or training; AGSSBOX = estimated number of hours experience at an AGSS gunner station; COMBAT = estimated number of combat hours; FLYTIME = estimated total number of flying hours; FLYTLM = estimated number of flying hours in the month prior to the survey; and FLYTNVG = estimated number of flying hours using NVGs.

The Survey

The survey was designed to capture both quantitative and qualitative information about the functionality and fidelity of the AGSS. A brief description of the data collection tool follows, and an abbreviated version of the survey appears in Appendix A. The survey was divided into nine sections: (1) background information, (2) helmet, (3) trainee stations, (4) IOS, (5) weapons simulation, (6) instructor/student interaction, (7) visual system, (8) training capability, and (9) miscellaneous.

The **background information** section included questions regarding the participant's age, current responsibilities, crew position, AGSS experience, flying experience, visual history, and past experience with unusual physiological symptoms (e.g., dizziness or blurred vision) during flight, after flight, and during everyday activities (e.g., reading).

Representing a primary component of the AGSS, the **helmet** section of the survey was fairly detailed and thorough including subsections on helmet component breakage and malfunctions, comfort and fit problems, the occurrence of problems with the electronic and communication cables, and adjustment requirements. For both the helmet breakage and comfort and fit subsections, specific helmet components (e.g., chinstrap or visor) were itemized for ratings. A 5-point scale (never, rarely, sometimes, often, always) was provided. Space was also

provided beneath each question so that the interviewer could write the details of subject responses, including under what circumstances any breakage occurred, suggestions about remedying noted problems, and ideas that participants had about improving the system. In the cable subsection, specific yes/no questions were listed about whether the cables interfered with or restricted task performance. The adjustments subsection provided space for specific time estimates required for fitting the helmet properly and aligning the visuals (during the subject's first and subsequent exposures), and whether any readjustments were required during AGSS sessions. At the end of the helmet section, space was provided for general comments.

The **trainee station** section included blanks for rating trainee station components, e.g., gun set-up, station mapping, etc. A 5-point Likert Scale 1 (poor) to 5 (exceptional) was provided. The verbal anchors of the scale referred to both similarity of the station component to the aircraft (the MH-53J or MH-60G as applicable) and the training capability of the component (see Table 2). Space was again provided for comments and/or suggestions.

Table 2. Survey Scale for Rating Judged Similarity to Aircraft and Training Capability.

Rating	Value	Definition
1	Poor	No similarity between simulator and aircraft. Provides negative training and has major deficiencies.
2	Min. Required	Little similarity between simulator and aircraft. Major modification is required to provide adequate training capability
3	Standard	Acceptable similarity between simulator and aircraft. Adequate training is provided.
4	Outstanding	The simulator and the aircraft similarity is nearly equal. Training capability is similar to that provided in the aircraft.
5	Exceptional	The simulator and the aircraft are virtually the same. Training capability is beyond expectations.

Like the helmet section, the **IOS** section was fairly detailed and inclusive. The first subsection contained questions about the location of the IOS outside the AGSS and the level of task saturation experienced by operators. The 5-point Never to Always scale was used, and space was provided for comments. The main IOS subsection included specific components of the IOS (e.g., the space ball) which were to be rated on their training effectiveness using a 1 (poor) to 5 (exceptional) point Likert Scale (see Table 3).

Table 3. Survey Scale for Rating Judged Training Effectiveness.

Rating	Value	Definition
1	Poor	Cannot train required tasks; system has major deficiencies.
2	Min. Required	Minimal training can be provided; major modification is required to provide adequate training capability.
3	Standard	Training capability is acceptable.
4	Outstanding	Most of the required tasks can be trained; few, if any, modifications required.
5	Exceptional	Training capability is above expectations, and tasks beyond those required can be trained.

The **weapons simulation** section duplicated the format of the trainee station section, i.e., specific components were rated from 1 (poor) to 5 (exceptional), using the scale illustrated in Table 2. Each component was rated separately by gun type (i.e., .50 cal and 7.62 mm) to account for any judged differences between the two.

The **instructor/student interaction** section was very brief. It included six yes/no questions about instructor ability to communicate with students from the IOS, and student ability to communicate with instructors and each other while in the AGSS.

The **visual system** section had two main subsections. The first was a repeat of the physiological symptoms portion of the background information section with the AGSS as the context, e.g., Did any of the following symptoms (e.g., dizziness) occur *during* or *after* training in the AGSS? This subsection was followed by a number of visual system elements and qualities (e.g., visual contrast) with space provided for judged ratings and comments on both day and NVG night training quality. Due to limited variability between the day ratings and the NVG night ratings, we primarily used the day ratings. However, some exceptions (e.g., responses related to day and night FOV) are noted in the text.

The **training capability** section included 39 required AG and FE skills that were selected based on analysis and discussions with AG and AGSS SMEs. Space was provided for participants' 1 (poor) to 5 (exceptional) assessments (see Table 4) and comments on the training capability of the AGSS for the skills under both day and NVG night conditions.

Table 4. Survey Scale for Rating Judged Training Capability for Specific AG/S Skills.

Rating	Value	Definition
1	Poor	Cannot train this skill in AGSS.
2	Min. Required	Only minimal training on this task provided in the AGSS.
3	Standard	Acceptable training provided on this task in AGSS.
4	Outstanding	Training provided on this task is above expectations.
5	Exceptional	Training on this task is beyond expectations due to capabilities of the AGSS not available in the aircraft.

The final section was a **miscellaneous** section. It included questions on the overall feel of the AGSS, the motion system, and whether subjects experienced any disorientation in the AGSS.

Data Collection Procedures

The survey was conducted using one-on-one guided interviews. All of the interviews were conducted by the primary author. The process began with both written and oral instructions to the subjects, including information about the confidentiality and purpose of the survey. Each subject read and signed a statement of informed consent. The participants were then asked to make their ratings and comments based on their subject-matter expertise and their experiences

with the AGSS. The interviewer stressed the importance of making candid device assessments and the fundamental goal of improving the system and its use by students and instructors.

Each interview was conducted using the same format and following the same topical order, i.e., from the background information section through the miscellaneous section. However, some sections and/or questions were skipped if the participant did not have experience with the device in that capacity (e.g., as an instructor/operator or using the device under NVG conditions). The interviewer prompted comments associated with extreme rating values. Responses were written directly on the survey by the interviewer. Most interviews lasted 1-2 hrs (the minimum was 40 min and the maximum 117 min), depending on the subject's amount of experience with the device. Those with more device experience tended to take longer to interview.

Choice of Analysis

The survey contained three types of quantitative responses: (a) yes/no responses; (b) never, rarely, sometimes, often, always scale ratings; and (c) 1 (poor) to 5 (exceptional) Likert Scale ratings. In addition, each participant provided researchers with a substantial amount of qualitative information, including their informed opinions about device components or features, particular problems, and often suggested solutions. There were very few questions that simply required a yes/no response, and for these we simply report frequency counts.

For the scaled responses, we were faced with more complex analytical issues. There were two critical challenges that had to be met. One, the quantitative information had to be logically linked to the qualitative information. Two, the selected analysis or analyses had to reflect both the positive and negative comments and ratings concerning the AGSS. This was necessary to ensure that the evaluation would yield a fair, impartial assessment of the device's capacity and worth to the training community.

In order to accomplish these goals, we selected two statistical techniques to analyze our rating data, one for the AGSS component ratings and the other for the AGSS training capability ratings. First, we chose the Kolmogorov-Smirnov, one-sample, goodness-of-fit test (Hays, 1988; Siegel, 1956) to analyze AGSS system component ratings. The Kolmogorov-Smirnov is a nonparametric test of the extent to which an observed distribution of scores deviates from some expected distribution. For each of our analyses, we used the Kolmogorov-Smirnov analysis to test whether the obtained rating distribution was significantly different from a uniform rectangular distribution. This analysis lets us determine whether the observed ratings for a given survey item were significantly bunched toward the positive end of the scale. Importantly, the Kolmogorov-Smirnov technique preserves the ordinal properties of the original rating scale, making it a more powerful test than the traditional chi-square test. In addition, due to the nature of the scale use by our participants, i.e., their limited use of extreme scale values, we chose to collapse the scale responses into three categories. We combined the "1s" and "2s" into a single category and we combined the "4s" and "5s" into a single category. The Kolmogorov-Smirnov analysis could still be applied to these data without any loss of statistical power. Comparisons were done against a fairly liberal alpha-level of .20.

Second, hierarchical cluster analysis was used to analyze the training capability ratings. The primary goal of cluster analysis is to identify homogenous groups of objects, in this case skills, based on distances among the objects. We used hierarchical clustering analysis to identify distinct skill clusters. The main steps of this approach were: (a) transforming the rating values provided by the subjects into z-scores, thereby appropriately weighting each participant's use of the scale; (b) calculating the distances between all possible pairs of skills; and (c) combining the skills into clusters or groups. In hierarchical cluster analysis, all objects begin as separate clusters where there are as many clusters as there are objects. At each iteration (or step) of the analysis, an object is added to an individual cluster or two clusters are combined (Norusis, 1993). There are several methods for combining clusters. We chose the between-group linkage approach which ensures that at each step cases are combined so that the average distance between all cases in the resulting cluster is as small as possible.

RESULTS

Overall Findings

Before discussing the specific results from each section of the survey, we present an overview of our major findings (see Appendix B for Raw Rating Data). Table 5 summarizes the results from the five major AGSS systems assessed and the overall assessment of the device's Training Capability. Besides the average overall rating which are generally acceptable, the table gives our general assessment (inferred by the researchers from participants' comments and ratings) and representative comments for each system.

Table 5. Summary Assessments for Each Major Survey Section.

System	Mean Rating (1 - 5)	Assessment	Representative Comments
Helmet	4.3	Good (when working)	⇒ When properly fit, everything should be okay.
Trainee Stations	3.8	Good	⇒ Much better than first design.
Instructor Operator Station	3.9*	Good (room for improvement)	⇒ Overall, it is nice. ⇒ Ownship flying with space ball is worthless.
Weapons Simulation	3.6	Needs Work	⇒ Not enough tracers per rounds fired. ⇒ Lead and lag problem.
Visual System	3.2	Faulty	⇒ Can't see targets until they are too close even with instructor input.
Training Capability	3.5	Good (Qualified)	⇒ Primary impacts will be on crew coordination, scanner calls, and target acquisition if visual problems fixed.

*Note. Represents an inversion of the subject responses (i.e., never to always) to make it parallel to other component ratings.

Starting with the helmet, we see that its overall rating was quite high, making it the highest rated AGSS system. From these ratings, we gave it a general assessment of "good." However,

low ratings for certain essential parts of the helmet, as well as participant criticisms, required us to include the "when working" caveat in our assessment. As discussed more completely below, critical components of the helmet (e.g., the head-tracker and CRTs) are subject to frequent breakage and/or malfunctions. Moreover, due to the newness of the device, the fitting and aligning processes are fallible which can lead to additional helmet problems (e.g., discomfort).

The mean rating for the helmet was determined in a different manner than the other systems. For the trainee stations, IOS, weapons simulation, visual system, and training capability, we asked participants to rate each system overall and averaged their responses to this question. In order to provide the overall mean rating that appears in Table 5, we summed participant responses to each of the helmet questions and divided by the number of questions. We believe this measure provides an appropriate overall SME assessment of the helmet.

The trainee stations received a fairly high overall average rating. Indeed, participants' comments were consistent with this high rating. It is perhaps a subtle distinction, but the majority of the comments focused on issues that could make the trainee stations *better*, rather than flaws about the design and functionality of the stations themselves, leading us to the unqualified assessment of "good."

The IOS had a slightly higher overall mean rating than the trainee stations. However, we assessed it as "good" with a "room for improvement" qualifier because particular features (discussed later) were given unacceptable ratings by participants. In addition, although some of the comments were simple suggestions for *improving* the training capability of the IOS (as we saw with the trainee station comments), many focused on changes that would *enable* training.

The overall "needs work" assessment of weapons simulation came primarily from the frequently cited modeling deficiencies of the bullet path (described later). The fairly high overall average rating of weapons simulation, despite this rather major problem, stems, we think, from the fact that many of the gunnery-related training capabilities of the AGSS simply did not exist prior to its introduction.

Survey participant comments and the somewhat lower ratings led to an overall assessment of the visual system as "faulty." Participants noted the tremendous importance of visual input for many AG/S tasks, and given the current quality of the AGSS visual system, the level of training that could be provided by the AGSS for many AG/S tasks was severely limited.

Finally, overall training capability of the AGSS was assessed as "good" with qualifications. That is, participant comments and ratings reflected overwhelming agreement that the training *potential* of the AGSS was tremendous, especially in the areas of crew coordination, target identification, and target acquisition. However, at least in terms of the latter two skills, the potential could not be fully realized until (as mentioned) improvements were made to the visual system.

To further substantiate the average ratings and the general assessments of each AGSS system, provided in Table 5, we have divided the rest of the survey results into two main sections: a component rating analysis and a qualitative summary of participant comments. The component rating analysis unveils both the positively and negatively rated features of the AGSS. In addition,

this analysis reveals features of the AGSS that received "standard" or "acceptable" ratings (i.e., neither significantly positive nor negative) that in conjunction with the participant comments (detailed in the next section) suggest several AGSS features which may require modifications. Briefly, the ratings and qualitative analysis illustrate that: (a) most features of the AGSS are acceptable for training, but may benefit from improvement; (b) quite a few AGSS features are superb; and (c) the AGSS, overall, functions fairly well as an AG/S training medium.

Analysis of System Ratings

As explained in the Choice of Analysis section, we chose the Kolmogorov-Smirnov one-sample test for goodness of fit (Hays, 1988; Siegel, 1956) to analyze the component rating data for each system. Because this technique retains the ordinal nature of the data inherent in the rating scale, it is more powerful than the traditional chi-square statistic. It also allows us to combine data from adjacent cells (i.e., the "1" and "2", and "4" and "5" ratings) without sacrificing statistical power. We have organized the component ratings results into five subsections corresponding to each of the AGSS systems—Helmet, Trainee Stations, IOS, Weapons Simulation, and Visual System.

Each subsection is organized around a table that depicts the results of the Kolmogorov-Smirnov one-sample test. Within each table, we indicate the system component that is rated, the number of participants who rated the component (N), the maximum deviation (Max. D) between the expected and observed cumulative probability distributions, and the two-tailed probability level for that deviation. When a probability level is not stated, this means that the ratings associated with that component were neither significantly positive nor significantly negative. In other words, participants provided "acceptable" ratings for these components. These components, as well as the features receiving significantly negative ratings, are discussed further in our qualitative analysis of participant comments.

It should be noted that the items associated with negative deviations (though still statistically acceptable) are also identified through this analysis. Given the level of development of the device (i.e., judged RFT for stand-alone training), it stands to reason that many components are *exceptional*, while a majority of them are *acceptable*, but could be improved. Perhaps the most remarkable finding, however, given the one-of-a-kind nature of the AGSS and the novel use of VR technology in the AG/S training realm, is the fact that only **two** components of the AGSS were rated significantly poor. We briefly describe the results of the rating analyses for each system below.

Helmet

Collapsing across two subsections of the survey (helmet malfunctions and helmet comfort and fit), 17 helmet characteristics were rated for frequency of problem occurrence. All but four characteristics had low levels of reported problem occurrence, i.e., were significantly positive (see Table 6).

Table 6. Helmet Rating Analysis.

Component	N	Max. D	Prob.
Chinstrap (malf.)	11	.670	.01
Chinstrap Chafing	11	.488	.01
Chinstrap Choking	11	.579	.01
Comm. Cable	11	.379	.05
CRTs	11	.215	
Electronics Cable	11	.397	.05
Eye Piece Combiner	11	.397	.05
Eye Piece Misalign.	11	.670	.01
General Comfort	11	.397	.05
Head-tracker	11	.215	
Helmet Pads	11	.488	.01
Hot Spots	11	.306	
Neck Fatigue	11	.579	.01
Helmet Fit	11	.306	
Slippage	11	.397	.05
Unbalanced	11	.579	.01
Visor	11	.488	.01

The four bolded, italicized components—CRTs, head-tracker, hot spots, and helmet fit—failed to receive reliably positive ratings from the Kolmogorov-Smirnov test. As a result, we will focus on these areas when discussing participant critiques and recommendations for the helmet in the next section.

Trainee Stations

Of the six trainee station components shown in Table 7, only one (gun feel) received a reliably positive rating. The others failed to achieve significance in either direction, and, as such, achieved "standard" ratings (with positive trends). As the comments will illustrate, the current development of the trainee stations is acceptable for training, but participants make many insightful remarks regarding potential improvements.

Table 7. Trainee Stations Rating Analysis.

Component	N	Max. D	Prob.
Gun Feel	11	.667	.01
Gun Set Up	11	.242	
Mobility in Station	11	.242	
VR A/C Interior	11	.303	
VR Other Stations	11	.242	
Station: Overall	11	.302	

Note. Crew seats and crew harnesses were not included in this analysis due to the few number of participants who had used these components in the AGSS. They are, however, discussed in our qualitative summary.

IOS

As shown in Table 8, the IOS runs the gambit of possible ratings. Several features were rated significantly positive (instructor screen, layout; crew performance page; gunner performance page; and IOS overall), one was rated significantly negative (the space ball for ownship flying), and several features were rated "acceptable." In addition, it should be noted that while all the other components that were judged "acceptable" to this point have had positive maximum deviations, the second instructor position of the IOS is the first acceptably judged component to have a negative deviation. This may indicate that the second instructor position needs more improvement than the other acceptably rated components. Later, we shall see that comments from participant substantiate this interpretation.

Table 8. IOS Rating Analysis.

Component	N	Max. D	Prob.
Instructor Screen, Content	8	.295	
Instructor Screen, Layout	8	.420	.10
Second Instructor Position	7	-.238	
Space Ball Models	8	.295	
Space Ball Ownship	9	-.556	.01
Station Layout	8	.333	
Student Screens, Content	8	.295	
Student Screens, Layout	8	.303	
PAGES:			
Crew Performance	8	.545	.10
Flare Monitoring	7	.333	
Ground Track Map	8	.333	
Gunner Performance	8	.420	.01
Threat Status	7	.333	
IOS: Overall	8	.420	.10

Weapons Simulation

Weapons simulation was assessed for both the .50 cal and the 7.62 mm guns. Participants' ratings did not vary across the gun types, so each feature is simply treated as an assessment of the general weapons simulation of the AGSS. Twelve individual aspects of AGSS weapons simulation as well as gun simulation overall were rated in terms of their fidelity and training effectiveness.

As shown in Table 9, analyses of the weapons simulation revealed a wide range of feature rating distributions: five subsystems were rated significantly positive (including guns overall), three were rated acceptable with positive trends, and four were rated acceptable with negative trends (indicated in the table by having gray-shaded Max. D cells). As discussed in the next section, the latter four gun features (gun alignment, gun pivot point, target acquisition, and tracers) were the primary focus of participant criticism in terms of weapons simulation.

Table 9. Weapons Simulation Rating Analysis.

Component	N	Max. D	Prob.
53 Gun Position	10	.266	.15
Air Stream Effects	11	.302	
Ballistics	11	.243	
Gun Alignment	11	-.152	
Gun Controls	11	.575	.01
Gun Pivot Point	11	-.061	
Gun Recoil	10	.333	.20
Gun Sounds	11	.333	.15
Gun Weight/Feel	11	.302	
Target Acquisition	11	-.122	
Tracers	11	-.122	
Guns: Overall	11	.333	.15

Note. Gun Position 60 was not included in this analysis due to the few number of participants qualified to rate this feature.

Visual System

Twenty-four specific elements of the visual system were rated for their training utility under both day and NVG night conditions. The differences in participants' ratings of the visual system did not vary between day and NVG night use, and therefore, are reported as general assessments of each feature.

The visual system was clearly the AGSS system that was associated with the greatest amount of participant dissatisfaction. Three points from Table 10 endorse this conclusion. One, ratings for object detection, a key requirement for numerous AG/S tasks (e.g., friend vs foe distinctions), were reliably negative. Two, six other visual system features, although, "acceptable," show negative deviations. (These are indicated in the table by having gray-shaded Max. D cells.) Three, only 5 of 24 features achieved significantly positive ratings. Of these, four were at the most liberal probability level used in our survey analysis. The visual system was also a source of many participant comments and critiques which are detailed in the next section.

Table 10. Visual System Rating Analysis.

Component	N	Max. D	Prob.
Alignment	11	.148	
Brightness	11	.330	.20
Contrast	11	.057	
Distance Perception	11	.125	
FOV	11	.330	.20
Image Clarity	11	.215	
Image Color	11	.148	
Image Stability	11	.306	.20
Object Detection	11	-.306	.20

Table 10. Concluded.

Object Resolution	11	.239	
Scene Clarity	11	.057	
Scene Completeness	11	.239	
Scene Continuity	11	.148	
Scene Depth	11	.215	
SPECIFIC OBJECTS:			
747	9	.330	.20
Explosions	11	.488	.01
Hind-D	10	.170	
Jeep	10	-.070	
Roads	11	-.057	
Runways	10	.270	
SAMs	9	-.003	
Trees	11	-.148	
Truck	9	-.114	
Visual Resolution	11	-.125	
Visual System: Overall	11	.239	

Problem Areas: Comments and Recommendations for Improvement

This section builds on the previous section by discussing the participant comments associated with each of the features identified in the Kolmogorov-Smirnov analysis as having either negative or "acceptable" ratings. We list the number of participants reporting problems with a feature "sometimes" or more when the participants were required to use this scale. In terms of our 5-point Likert scale, we report the number of participants (typically out of 11) who rated a given component/feature as a "3" or less. We then report some of the criticisms cited for each component discussed, followed by recommendations for improvement.

The best match between rating scores and the frequency and content of comments was achieved by grouping "3" ratings with the more negative "1" and "2" ratings (as described) and using a liberal Kolmogorov-Smirnov criterion of $p < .20$. This was, therefore, adopted as our decision rule for including topics in this section. The tendency to rate an area as a "3" (or acceptable) and still provide negative comments may reflect the RFT status of the AGSS which connotes that "standard" (or "3") criterion levels have already been officially met. Additionally, there were several survey questions associated with the helmet and the IOS which were not amenable to the Kolmogorov-Smirnov analysis; the responses and statistics related to these questions are also reported below.

Helmet

Seventeen aspects of the helmet were explored for either malfunctions or problems with comfort and fit. We also asked several questions about problems associated with the helmet communication and electronic cables and the required helmet donning time.

Helmet Components

Comments. Seven helmet components were rated according to frequency (from "never occurred" to "always occurred") of breakage or malfunctions. Five of 11 survey participants reported problems "sometimes" or more with only two helmet components: the head-tracker and the CRTs.

With regard to the head-tracker, two of the main problems identified in participant comments were that it malfunctioned frequently during AGSS sessions and that it did not keep up with required scanning rates. One participant reported that certain locations in the AGSS cabin were problematic, creating diagonal lines in the visual field.

The main problems noted were CRTs performance deterioration over time, CRT failure rate, and perceptual mismatches from using old and new CRTs together. For example, one participant reported that "sometimes one [CRT] is better than the other so your eyes see two different things, and that this is more and more of a problem as time goes by." Another individual stated that "the new ones [CRTs] burn out quickly, creating distracting blotches and some disparity between the two eye pieces."

Recommendations. From our perspective, it is critical that the performance of the head-tracker and CRTs should, at the very least, be monitored over time. In addition, the CRTs could be replaced more frequently, and in pairs, to prevent large visual discrepancies between the two eyes. For the head-tracker, more recent technology with faster update rates should perhaps be explored. These recommendations, however, require substantial additional funds to be invested in the AGSS. Until the addition of funding, a number of clever, innovative "work arounds" may offer interim solutions. During our observations of training, for example, one particularly adept instructor recommended that students use an "NVG scan," which is a slower scan, to accommodate the lag between the head-tracker and student scanning rates. In this way, students can maintain "procedural fidelity" without creating their own simulator-specific "work arounds" that could interfere with proper skill performance in the aircraft. Also, if the CRTs cannot be replaced more frequently, students should be warned about possible visual discrepancies. From our experiences in other training environments, students are much more receptive to new training technologies when both the virtues and limitations are discussed up front.

Helmet Comfort and Fit

Comments. The frequency of problems associated with ten aspects of the helmet comfort and fit were rated, again from "never" to "always." Three aspects are worth discussing because of the comments associated with each. They are the helmet pads, the occurrence of hot spots, and the chinstrap. These are all related to the results from the Kolmogorov-Smirnov analysis which indicated that helmet fit is only "acceptable."

The helmet pads were frequently cited in participant comments as being inadequate, with their method of attachment to the helmet singled out most often. Participants noted that the velcro tape comes off inside the helmet, and that the pads unglue and rip. Others reported that the pads are hard and uncomfortable. In responses to other queries about poor helmet fit or

helmet slippage, several participants also suggested that the helmet pads were the primary culprit. Indeed, one participant stated directly that the reason the helmet fit poorly was due to hard pads. Despite the frequent mention of helmet pad problems, only two participants reported problems with the comfort and fit of the helmet pads "sometimes" or more.

The second aspect of note was the report by four survey participants of hot spots when using the AGSS helmet even after short (e.g., 30 min) AGSS sessions. The helmet pads were again cited as one reason for the hot spots. However, several respondents, including those who did not rate hot spots as a problem, singled out the helmet's method of use as a key factor. They suggested that if the appropriate adjustments and sizing were made, hot spots could be avoided, such that "with proper pads and proper adjustment these [hot spots] didn't occur."

Although only two participants reported major problems with the chin strap, it is worth mentioning because of its relationship to poor helmet fit. Participants proclaimed: "it's uncomfortable," "it cuts into your skin," "no real padding," or "needs a different kind of padding." They also suggested that the helmet's method of use influenced their ratings. For example, one participant said, "If the chinstrap is upside down with the fabric touching your face, this is a problem, and this can occur if it [the helmet] is put on improperly or moves during training."

Recommendations. Short of acquiring new helmets or integrating the CRTs and head-tracker into the same helmets worn in the aircraft, all of the above complaints (helmet padding, hot spots, and chin strap discomfort) could be remedied by improving the quality of the pads and their method of attachment to the helmet. The helmet fitting and adjustment process also needs to be monitored closely. Moreover, as the AGSS is incorporated into MQ and Annual Refresher training, more standardized procedures should be established to help alleviate problems and/or discomfort that arise from improper fit helmet.

Helmet Electronic and Communication Cables

Comments. Two questions concerning the helmet cables are notable because of the comments associated with each. First, four participants reported that the current cable length limited their amount of normal movement around the aircraft. Respondents qualified their answers, stating that for the subset of tasks performed in the AGSS, their movements were not hindered. One participant explained that "cable length is not too much of a problem because of what is done in the AGSS, but amount of movement is less than in the aircraft. Tasks requiring movement are things like switches, weapon malfunctions, and getting equipment." Some cited particular stations or configurations (methods of use) as more problematic than others. For example, one participant reported that the range of motion in the tail position compared to the aircraft was reduced in the AGSS as a result of the cable length. The MH-60G crewmember interviewed also noted that when the AGSS was in the MH-60G configuration, the range of motion from seat to door in the left and right positions was less than the aircraft.

Second, three participants reported qualified problems with the amount of pressure they felt from the cables tugging at the backs of their head when performing tasks in the AGSS. Those who encountered problems with this feature stated various caveats, such as, problems only

occurred during extreme movements or that the cables were distracting but they would probably get used to it. However, one participant did report that he felt like the cables "kept getting caught on something," and that he was forced to stop what he was doing in the AGSS and unhook them from his back two or three times during training.

Recommendations. Due to the small number of respondents reporting cable length problems associated with task performance or discomfort, there is some question as to whether the cables really are a problem. Considering the participants' comments, it seems that if only the appropriate AGSS-supported tasks are performed, the cable length is satisfactory. However, further consideration of cable length for the tail position seems warranted. Given some of the specific comments, longer cables may be necessary for the tail position to perform his/her required tasks. In addition, a few respondents did suggest that a means of tethering the various cables up off their shoulders may be beneficial for the times when the cables did get caught, especially for the MH-60G configuration, where the crew seats are used.

Helmet Donning and Adjustment

Comments. Included in the helmet subsection of the survey were questions that asked participants to estimate the number of minutes required to put on and adjust the helmet during their first and subsequent encounters with the AGSS. Participants also indicated whether readjustments were necessary during training sessions. Average donning time for the first use was 11.1 min; the average for subsequent sessions was 3.2 min. The reduction in donning time was statistically significant ($t = 4.15$, $p < .01$, $df = 9$, with one participant excluded because he only wore the helmet once). In addition, three participants reported the need to readjust the helmet "sometimes" or more during AGSS sessions. (Five additional participants noted problems "rarely" and some of their comments are included in the table below.) Three categories of adjustment problems appeared in participants' comments. These involved issues of alignment, the air pump, and familiarity. Table 11 summarizes the participants verbatim responses.

Table 11. Survey Participant Verbatim Responses Regarding Helmet Adjustments.

Category	Participant Responses
Alignment	⇒ Had problems with the alignment process. ⇒ Figuring out what alignment means seems to be the biggest hurdle when first setting up the helmet. ⇒ It seemed off, but I didn't want to adjust it because I didn't want to screw with the alignment.
Air Pump	⇒ Miscellaneous problems with the air pump. ⇒ Adjusting pump. Normal head movements changes how helmet feels, makes you adjust comfort level, often too tight. Found myself adjusting it every 5 minutes or so. ⇒ It was too tight and I had to release some air pressure. ⇒ Pumped it up too tight initially and let air out as flight progressed, ended up releasing most of the air. ⇒ Two hot spots in the back were relieved by letting out air.
Familiarity	⇒ Once familiar with its operation, it is okay. Operator error caused some initial problems. ⇒ Had to shift it a bit just to get it comfortable. If it is not set up correctly, you will have serious problems.

Recommendations. It is not surprising that the helmet adjustment process takes longer during the first use, nor is it unexpected that readjustments are required during training sessions. Nevertheless, AGSS curriculum developers need to be aware of these time requirements so that tasks and objectives can be tailored to the allotted time periods. As mentioned previously, the proper adjustment and alignment of the AGSS visual input system (e.g., CRTs) is critical. Here again, proper alignment procedures are recognized as a primary factor for reducing readjustments during AGSS flights. Two main recommendations are made in this regard. First, the 58 TRSS should attempt to standardize and document the fitting and aligning process so that when knowledgeable instructors and maintenance support relocate, their knowledge does not leave with them. Second, the squadron should provide additional (or separate) time prior to training to familiarize trainees with the helmet, VR technology and terminology, and alignment procedures.

Trainee Stations

Seven individual trainee station components (gun feel, gun set-up, mobility in station, VR aircraft interior, VR other stations, crew seats and crew harnesses) were assessed in our survey. Five are discussed below based on the Kolmogorov-Smirnov analysis and participant comments.

<u>Gun Set-Up and Feel</u>

Comments. Seven participants rated gun set-up as a "3" or less. The primary problems identified concerned gun alignment and adjusting the gun barrels properly within the AGSS. Similarly, six participants rated the virtual mapping of the surrounding gunner stations as a "3" or less. The main criticism involved the virtual mapping of the other players in the aircraft environment. Specifically, there is an FE "mapped" into the middle seat when one looks forward in the AGSS virtual environment, but no other members of the cockpit nor the backend are "mapped." Several individuals commented on this selective mapping. Some participants suggested mapping players into *all* crew positions (i.e., model a pilot and copilot in the other cockpit seats), while others advocated eliminating the mapping of virtual players altogether.

One participant provided two important insights regarding the general fidelity of the trainee stations. First, he noted that he was more likely to downgrade the fidelity of the other stations (vs his own) because he could more easily "nitpick" what should and should not be there as he looked around. Secondly, he noted that if he was looking at the other stations and not out his window, then he was not doing his job. The tradeoffs between selective fidelity and "time on task" may need to be explored further as the AGSS becomes more fully integrated into the training curriculum.

Recommendations. First, the difficulties with gun barrel alignment can be reduced by standardizing and better conveying the general alignment process. In terms of mapping other players, the two choices seem to be: (a) either map all the members of the cockpit in the AGSS (which may not be possible given current IG modeling limitations), or (b) map none of them. Here, again the tradeoffs of selective fidelity should be explored. For example, mapping all of the cockpit players may increase user-acceptance of the device which may in turn have a beneficial effect on the training effectiveness of the device.

Mobility, Seats, and Harnesses

Comments. Next, six participants rated their mobility (already briefly mentioned in reference to the helmet cables) at the AGSS gunner stations as a "3" or less. The primary criticism was that there is less mobility in the AGSS than in the aircraft. Several different reasons were cited, including cable length, inhibitions about having an expensive helmet on one's head, and differences between the virtual and physical world. Regarding the latter, it appears as if one can put one's head out of the AGSS windows in the virtual aircraft although the simulator's structure does not allow this. However, most respondents reiterated that given the tasks performed in the AGSS, reduced mobility was not that much of a problem.

Due to the limited use of the AGSS in the MH-60G configuration, only five participants were qualified to rate the functionality and fidelity of the AGSS seats. Yet, four of them rated the seats as a "3" or less. The primary problem was that while the seats met the design specifications for the AGSS, they were still not comparable to the aircraft. As a result, participants expressed concern about their durability.

The harnesses were also only rated by five participants, and again four of them rated the harnesses as a "3" or less. Two main points arose from individual comments: First, the harnesses seemed to be of poor quality. Second, they simply were not used much. Respondents noted that while the harnesses were a part of the critical design review (CDR) requirements for the AGSS, their purpose within the AGSS was unclear.

Recommendations. If the harnesses and seats are going to receive regular use, the primary recommendation is to improve their quality to support AGSS training throughput.

IOS

Thirteen individual features of the IOS were rated on training utility. Six are discussed below based on the Kolmogorov-Smirnov analysis and participant comments.

Screen Layout

Comments. Four out of eight participants rated the student screen layout at the IOS as a "3" or less, and three out of eight rated the general layout of the IOS as a "3" or less. The primary critique was that, while the current layout was functional, better layouts were possible. One individual noted that due to the height and location of the instructor information output screen (see Figure 6), he had to get out of his seat to make some control inputs.

Recommendations. There are two main recommendations for improving the IOS layout and making the IOS more "user friendly." First, if the IOS layout remains as shown in Figure 6, AGSS training would be greatly enhanced by using two instructors for the training sessions. One instructor would be responsible for running the AGSS and the other for observing, instructing, and role playing. (We make this same recommendation later, in response to instructor-reported levels of task saturation at the IOS.) Second, if additional funds are available or the AGSS is moved, a more ergonomic arrangement of the screens was suggested by a survey participant, and

that view is endorsed here. The proposed layout (see Figure 8) would enable instructors to better divide their attention between IOS inputs and instruction, while also eliminating the instructor's disruptive requirement to get out of the seat to make inputs during training.

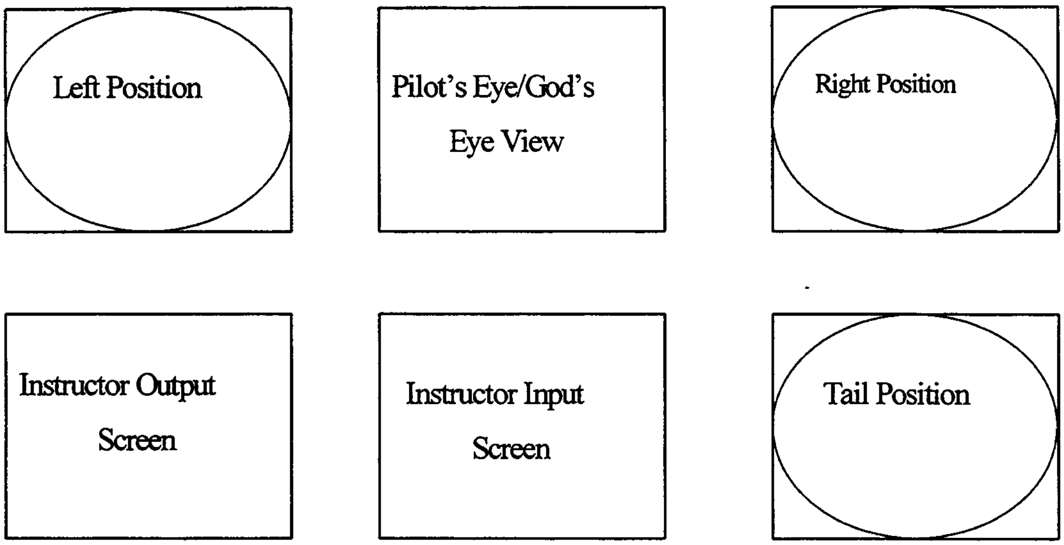

Figure 8. Recommended Improved Layout of IOS Screens.

<u>**Space Ball**</u>

Comments. The most unanimously agreed-upon poor feature of the IOS was the space ball for flying ownship during stand-alone AGSS training. Nine out of nine participants rated the space ball as a "3" or less, and it was singled out by the Kolmogorov-Smirnov analysis as having significantly negative ratings. This result is in contrast to only three of nine who rated the space ball as a "3" or less for flying moving models and the "acceptable" result of the Kolmogorov-Smirnov analysis for space ball flying of moving models. This is a prime example of how the method of use of a particular AGSS feature has a great influence on its judged effectiveness. The central reason given for the overwhelming displeasure with the space ball for flying the ownship was the poor software modeling of aircraft aerodynamics which manifests itself as a tremendous difficulty for maintaining proper flight control using the space ball. The following excerpt is representative of the space ball critiques we recorded, and is illustrative of the problems and consequences of using the space ball for ownship flying during training:

> The big thing with space ball ownship flying is the MH-53J WST code that is used for the software modeling. This causes major problems if you are forced to fly with the space ball during stand-alone training with students. It is impossible to interact with students as you should. You [also] end up using the slew keys more often than you should which gives students artificial cues. . . Do anything to stay away from space ball flights. Get rid of space ball or make it fly more like a generic model.

Recommendations. With such unanimous displeasure associated with flying the ownship using the space ball, we strongly recommend that it either be changed or its use limited during

training. Several participants suggested simply replacing the space ball with a joystick, enabling quicker input adjustments and accommodations due to poor modeling of aircraft aerodynamics. However, at the AGSS's current level of development, this would require extensive and costly changes to the software (e.g., changing drivers). Another less optimal suggestion is to conduct AGSS training with minimal use of the space ball, either in the integrated mode—when the MH-60G or the MH-53J is the host cockpit—or using the record-replay function to run through prerecorded missions. This latter approach is, in fact, often employed during current AGSS training. Among its advantages, this method greatly increases the instructor's ability to: (a) focus on the students in the AGSS, (b) provide timely feedback, (c) use the performance monitoring pages, and (d) introduce moving models into the scenario. However, the interactive nature and realism of the flights are reduced because directional calls (e.g., break left) cannot be responded to unless it has been prerecorded. Use of the integrated mode, on the other hand, will solve many of the problems associated with the space ball for ownship flying. Yet this mode is still viewed as less than optimal since it is not presently integrated and (three) stand-alone AGSS rides are still a required part of the AG Mission Qualification training.

Second Instructor Position

Comments. There was extensive agreement among participants on lack of utility of the second instructor position at the IOS. Six out of seven participants rated this IOS feature as "3" or less. Comments focused on inability of instructors at this position to communicate directly with students in the AGSS. Echoing the thoughts of the other five displeased participants, one individual succinctly said, "You have the capability to hear, but you can't talk. This is dumb. Provide this capability."

Recommendations. In order to enable instruction and accommodate some of our other recommendations, the second instructor position *must* be provided the capability to communicate directly with the students in the AGSS.

Individual IOS Pages

Comments. Other IOS features rated as "3" or less by a number of survey participants were three IOS pages: flare monitoring, threat status, and the ground track map. Five of seven participants rated the flare performance monitoring page as "3" or less and four out of seven participants similarly rated the threat status page. For both pages, however, the comments primarily addressed the fact that they "just weren't used much," suggesting a degree of skepticism regarding content and utility of these pages. Five of eight participants, however, rated the ground track map page as "3" or less. The primary criticism of the ground track map page was its lack of waypoint representation.

Recommendations. A solution to the absence of waypoints on the ground track map page is simply to provide them as in some of the other simulators at the 58 TRSS. However, the AGSS lacks a navigation system, and without this capability, it is not possible to input waypoints. The costs to implement a one-of-a-kind navigation imitator on the AGSS would undoubtedly override any debatable benefits on a device such as the AGSS. Nevertheless, there is at least one potential solution given the current AGSS design specifications. One survey participant offered the clever suggestion of setting up inactive (or active) threats to mimic waypoints on the ground

track map page. Threats do appear on the ground track map and could be used to help navigation calls, especially for the FEs.

External Environment

Comments. Several questions were designed to tap into the existence of potential problems associated with locating the IOS outside the motion base of the AGSS (unlike other simulators at the 58 TRSS). Question topics included noise level, visual distractions, and the instructor level of task saturation due to the inability to see students and monitor screens for both student performance and aircraft performance. The only question having a large proportion of participants rating it as a problem "sometimes" or more was the level of instructor task saturation experienced at the IOS. Task saturation was noted by participants whether there was one student (5 of 8), two students (5 of 8), or three students (4 of 6) in the AGSS.

The mean levels of instructor task saturation experienced with one, two, and three students is shown in Figure 9. As can be seen, there is a linear relationship between the reported level of task saturation and the number of students in the AGSS. Thus, as the number of students in the AGSS goes up, so does reported level of task saturation. Although the comparisons between the means were not statistically significant, participant comments suggested that the demands of flying ownship, laying down threats, and monitoring students can wreak havoc on the level of training that instructors are able to provide students in the AGSS. Figure 9 also shows that the severity of reported task saturation increases when the one SME, who had a large role in the development of AGSS IOS and over eight years experience as a simulator instructor/operator, is removed from the calculations (i.e., the right bar graph of each pair in Figure 9).

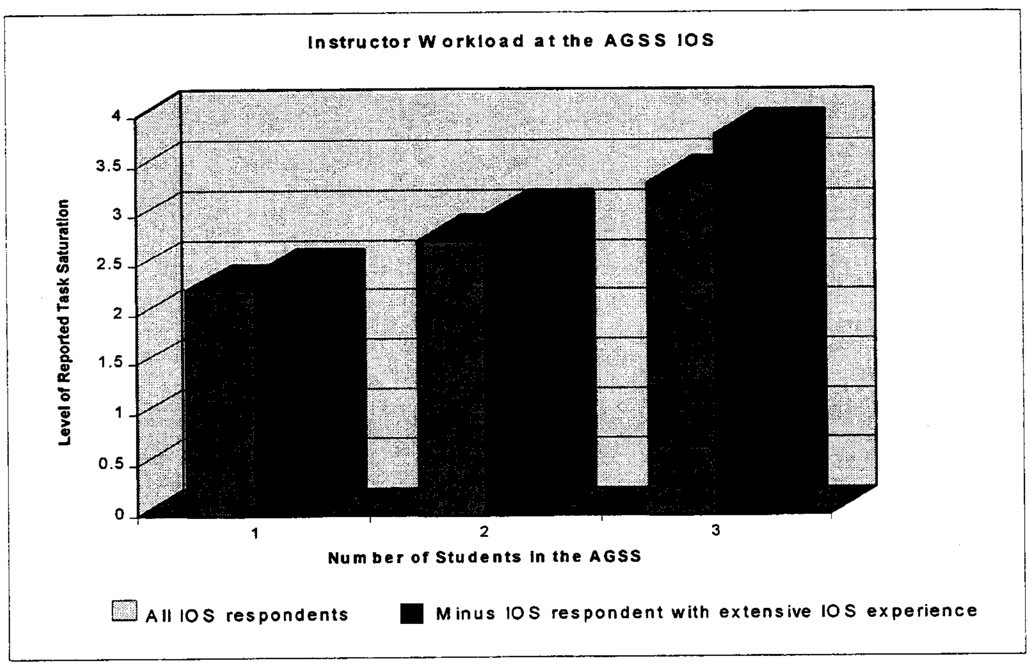

Figure 9. Reported Levels of Instructor Task Saturation with One, Two, and Three Students in the AGSS.

Recommendations. There are at least two potential solutions for reducing the level of instructor-reported task saturation: limit the number of students who are trained concurrently in the AGSS or add a second instructor at the IOS (as already mentioned). We view the first solution as inadequate. Although the instructor's ability to provide feedback and observe training is increased, the level of realism of training and the number of skills that can be practiced (e.g., Left, Right, Tail call responsibilities or crew communication) are significantly reduced. The second solution is really the best, provided the second instructor position is enhanced to include the ability to directly communicate with students in the AGSS. Two instructors at the AGSS would allow increased realism, better feedback, more role playing, and better use of the available AGSS capabilities.

Although administered as its own section during the interviews, questions concerning instructor/student interaction and the communication system are logically related to the above issues, so its results are noted here. Several yes/no questions about instructor and student ability to hear one another were asked. None of the participants reported significant problems with either hearing or understanding the students while at the IOS, nor were participants unable to hear or understand one another or the instructor while in the AGSS.

Weapons Simulation

Based on the Kolmogorov-Smirnov analysis and participant comments, six individual gun features are discussed below. The overall assessment of the weapons simulation is also discussed due to the number of participants rating it as a "3" or less.

Modeling Fidelity

Comments. Two related items, the ballistic model and tracer fidelity, both had a large number of individuals rating them as a "3" or less: eight individuals for tracer fidelity and six for the ballistic model. Although the specific comments for each element were different, a common problem was inadequate mapping of the projectile jump, or lead and lag, of the bullet's path. In particular, the problem arises from using F-16 (an aircraft with guns mounted on the nose) software for modeling the bullet path. In the MH-60G or MH-53J, two of the guns are mounted on the sides of the aircraft leading to different aerodynamics on the bullet. This requires different aiming procedures since a bullet fired from the side window of a helicopter does not travel in a straight line as it would if it were fired off the nose (or tail). Although most comments focused on this issue, and how the AGSS would be *better* if this were incorporated, one individual said: "The bullets go straight and this does not teach anything. You just can't replicate real guns." Other critiques about the tracer path and the ballistic model concerned the number of tracers per rounds fired, the different cues in the AGSS (compared to the aircraft), the inability to see tracers leaving the gun, and the existence of jerky visuals during target engagement.

Recommendations. The primary recommendation regarding the ballistic model is to improve it by incorporating lead and lag effects. Again, however, such a change requires extensive modifications to software and additional AGSS funding. Alternatively, if this is not an option, students may be instructed about the differences between the AGSS and the aircraft. The AGSS could be used as a potent illustrator to contrast the bullet's path in the aircraft versus the

simulator. Due to current IG modeling constraints, the limited number of tracers per rounds fired may also require additional "coaching."

Alignment

Comments. Another aspect of weapons simulation receiving almost unanimous displeasure was the alignment of the virtual gun with the physical gun in the data base, with nine participants rating it as a "3" or less. The two main criticisms were the (a) unfamiliar and unstandardized alignment process and (b) apparent degradation of the alignment during training.

Similarly, the alignment of the gun on its pivot point was rated as a "3" or less by eight participants. The main issues cited were that the gun "floats," the alignment process itself is poor, and it is necessary to make readjustments during flight. Many participants suggested that this problem was strongly related (again) to lack of understanding and definition of the appropriate procedures for aligning the gun position in the data base.

Recommendations. Again, as mentioned, we recommend improving and standardizing the alignment procedures to alleviate many of these problems. We would also recommend improving the modeling of the gun in the data base. (Note: Since the survey was conducted, the software modeling of the gun position has, indeed, been improved and there is no longer a gap between the gun and the pivot point [i.e., the "floating gun"]).

Targeting

Comments. Target acquisition was also surveyed as part of AGSS weapons simulation, with seven participants rating it as a "3" or less. The primary comments were related to poor characteristics of the visual system, as exemplified by: "really due to poor visuals," "associated with visuals," or "can't see targets until they are very close, does not equal reality, or even come close."

Four survey participants rated airstream effects as a "3" or less. The primary comments in this area were related to aircraft and simulator discrepancies (e.g., control loading) during AGSS development. (Note: Since the survey was conducted, this problem has also been remedied.)

Recommendations. The primary recommendation in terms of improving the target acquisition capability of the AGSS is to improve the quality of the AGSS visual system. This will be discussed in further detail in the next section.

Finally, seven participants rated the overall weapons simulation of the AGSS as a "3" or less. However, the Kolmogorov-Smirnov analysis indicated that weapons simulation was rated significantly positive. Participants' comments support this apparent contradiction. The overwhelming sentiment expressed in terms of weapons simulation was that participants were very enamored with the new capabilities of the AGSS—indicated by high participant ratings. They were, however, disappointed in several key features (the ballistic modeling, visual system, and alignment process) and this is clearly indicated in their comments. In essence, this combination of results is typical of any new technology assessment—participants recognized the AGSS's training potential, but were also well are of its current shortcomings.

Visual System

Comments. As indicated by the Kolmogorov-Smirnov analysis, various features of the visual system were rated "acceptable" or lower. We discuss several of these below, as well as any previously unmentioned differences between NVG night simulation and day simulation that participants' noted.

Eight participants rated object detail and visual resolution as a "3" or less. Comments highlighted the fact that the level of detail did not match the real world; this was particularly obvious for targets. As a behavioral consequence of this lack of detail, these eight participants also rated target or object detectability as a "3" or less. Comments focused on lack of detail and the inability to make friend versus foe distinctions unless objects were at an unrealistically close range. Particular object representations were also rated, including a 747, explosions, a Hind-D helicopter, jeeps, roads, runways, surface-to-air missile (SAM) sites, trees, and trucks. Not surprisingly, given the overall ratings of object resolution, seven of these objects were rated low by a large proportion of survey participants. The primary reason for the low ratings in each case was insufficient detail. Table 12 presents a summary of the data for each object. The shaded rows (runways and explosions) indicate the objects with the fewest number of low ratings.

Table 12. Specific Object Ratings and Representative Comments.

Object	Observed Number of Ratings of 3 or Less	Representative Participant Comment
747	5 of 9	None noted.
Explosions	2 of 9	⇒ Never get to see them in real life. ⇒ Secondaries are good.
Helicopter (Hind-D)	5 of 11	⇒ Needs more detail, a higher texture model. ⇒ Lacked clarity, couldn't tell if it was airborne.
Jeep	6 of 10	⇒ As targets okay, but if you had to tell between good guys and bad guys, you couldn't do it. ⇒ Was told it was there, but didn't recognize it.
Roads	8 of 11	⇒ Couldn't distinguish between roads and rivers. ⇒ Just brown lines.
Runways	4 of 9	⇒ Almost better than real life.
SAM Sites	6 of 9	⇒ Animation needs to be upgraded. ⇒ Could tell up close (400 ft), but farther away, problems.
Trees	9 of 11	⇒ Need work, a lot of variability. ⇒ Other trees in other visual systems are better. Trees are flat.
Truck	6 of 10	⇒ Not enough detail. ⇒ Could have been a white blur.

Similarly, we also asked about image resolution and detail level of the entire visual scene. Six of 11 participants rated this feature as a "3" or less. Comments included: "could be more stuff in there," "lack of detail," and "lack of realism."

A critical element of any visual system is its representation of depth. We asked about this feature in two ways. First, we asked for a general assessment of whether the visual scene provided meaningful depth information. We also examined the behavioral manifestation of this in terms of participants' distance perception abilities. Five participants rated the portrayal of meaningful depth in the visual scene as a "3" or less. Accordingly, participants' judged distance perception as poor, with six participants rating it as a "3" or less. Participants had different views concerning the primary culprit. Several individuals cited the above problems with object resolution as the key cause. Others blamed their perception difficulties on the "flat scene." Still others qualified their comments, saying that certain distances could not be judged but others could. For example, one participant said that judging distance from the aircraft to the ground was possible in the AGSS, but other aspects of distance judgment were difficult. The variability in responses led us to believe that perhaps the main problem with this visual feature was certain inevitable differences between the aircraft and the AGSS.

Related to both resolution and depth of the visual scene is visual contrast. Seven participants rated this feature as a problem. Participants' comments were fairly specific, interpreting their inability to discern visual contrast as a result of the limited detail in the visual scene and the lack of a three-dimensional scene representation. A particularly telling comment was, "My focusing is impaired, constantly fighting to focus, trying to grab at sharp detail, but not much there." One participant, however, did mention that visual contrast was satisfactory during the daytime scenes, but it was not sufficient during NVG night scenes.

Five of 11 participants rated visual brightness as a "3" or less. Like the above feature, and in accord with our framework (Figure 2), there appeared to be some disparity due to method of use. Specifically, NVG night scenes were the main source of the critical comments, e.g., "the virtual NVG scene is grayer than the NVG scene in the aircraft and the color balance seems off."

Visual scene clarity and image clarity were also judged as problematic by a number of the participants (7 and 5, respectively). Participants claimed that although the system was good in its present form, there was room for marked improvement.

The completeness of the visual scene was rated as a "3" or less by six participants. They qualified their responses to reflect discrepancies between a properly versus a poorly functioning IG. The central theme was that when the IG was functioning properly, the scene did not get chopped or clipped off. But when it was not working, "it would do some weird stuff."

Visual scene continuity was rated as a problem by seven participants, but the comments were not qualified by the status of the IG. Participants were primarily concerned about the update rate of the IG, maintaining that it seemed slow and that occasionally the scene had to catch up with their scanning rates.

Visual alignment ratings, as previously reported, were unsatisfactory. In this case, the assessment focused on the visual/virtual representation of the physical world, with six participants rating it as problematic. Most of the comments identified small details of the virtual environment that did not match the aircraft. One participant, however, said "that [the AGSS] was more two-dimensional than [he] would like and that it was not as three-dimensional as VR technology claims."

Image color was rated as problematic by six participants. The main complaints were that the colors looked "washed out" and that there were noticeable differences between new and old CRTs. Importantly, AGSS image color has been improved since the survey, but the issue of CRT breakage and decay still needs to be addressed.

Although rated significantly positive (see Table 10) by our survey participants, we probed the FOV feature further because of its importance in the fulfillment of AG/S tasks. We asked two yes/no questions regarding FOV for daytime and NVG night conditions. Seven of 11 participants reported that they did not achieve a full FOV for daytime operations, but only two of nine participants reported being unable to achieve a full FOV for NVG night operations. This likely reflects the fact that during NVG use, one's peripheral vision is already reduced and the AGSS visual system is able to mimic this. The primary concern during daytime operations was that even with their understanding of the visual system's constraints on FOV, participants were unable to see fully forward or aft because they could not "get their heads out of the windows" as many (particularly FEs) do in the aircraft.

Not surprisingly, seven survey participants gave low overall assessments of the visual system. The specific comments seemed to reflect the visual system features participants were most dissatisfied with, such as the CRTs, distance cues, visual contrast, etc. But despite their apparent dissatisfaction, several comments suggested that participants could train with the device as is, but there was room for "a lot of improvement."

Recommendations. Participant dissatisfaction with the visual system was quite pervasive. As a main component of the AGSS and given its criticality to AG/S tasks, a primary recommendation is to explore the visual system in further detail, to gain a better understanding of the many problems encountered by survey participants and which features are the most important to the fulfillment of AG/S skills. While many of the comments focused on definite inadequacies with the system (e.g., washed out color or faulty IG), others seemed to be related to misconceptions about the capabilities of simulation (e.g., discrepancies between real-world image and the virtual image). With a substantial percentage of the users (both instructors and trainees) of this device being new to simulation, it may be that many of their critiques have more to do with a lack of knowledge about simulation capabilities rather than inadequate device capabilities. This would suggest that additional or separate familiarization time be provided where the device and its capabilities are briefed. In addition, further exploration of the visual system would distinguish areas for which there are real problems with the hardware/software from those which are user-centered. Based on the survey and the skills the AGSS is designed to train, three visual system features require immediate attention: object detail, color quality, and visual continuity (or update rate).

We also recommend improving the FOV, but not by purchasing a new visual display. The main criticism of the FOV was the inability to see fully forward or aft in the AGSS. The primary reason for this was not the limited range of the HMD's FOV, but instead, it was the trainees' inability to get their VR helmets out the AGSS side windows and use head movements to expand their FOV, as presently done in the aircraft. (However, there is some disagreement among SMEs as to the actual frequency of this practice.) One solution would be to enlarge the AGSS windows to accommodate the VR helmets. While this would reduce the AGSS' physical fidelity with the aircraft, its *functional* fidelity would be much enhanced.

Motion

The miscellaneous section of the survey contained several questions about the motion system. Two questions and their responses offered some insight in this regard. First, six participants reported that the AGSS did not fly like the aircraft. Yet, eight participants reported being satisfied with the three-degree-of-freedom motion system. Combined, these two results led to the tentative conclusion that the limited motion base was not the primary reason why participants reported that the AGSS did not fly like the aircraft. Instead, they cited low vibration level, lack of gravity, and lack of seat-of-the-pants feel.

Physiological Symptoms

Self-reports of the frequency and severity of nine different simulator sickness symptoms (visual discomfort, headaches, double vision, blurred vision, disorientation, eye strain or fatigue, neck strain, stomach discomfort, and nausea) during and after AGSS sessions were obtained. To determine the number of subjects reporting symptoms, we first collapsed across all of the symptoms. We found that 54% of the survey participants reported symptoms sometimes or rarely, and 46% reported never having symptoms (both during and after AGSS flights). This is consistent with the literature on simulator sickness, where the percentage of individuals reporting symptoms across a selection of simulators has been observed between 10% and 60% (Kennedy, Lilienthal, Berbaum, Baltzley, & McCauley, 1989). Figure 10 depicts the reported incidence of simulator sickness symptoms *during* AGSS sessions.

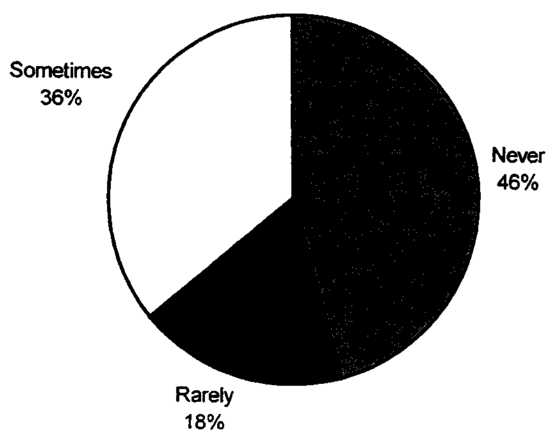

Figure 10. Reported Incidence of Any Simulator Sickness Symptoms *During* AGSS Training.

However, when individual simulator sickness symptoms were scrutinized more closely, only two symptoms were reported by a significant proportion of the participants during AGSS training, and none were significant after AGSS training. Eye strain and visual discomfort were both reported "sometimes" or more by five participants. Interestingly, eyestrain has been shown to be the most commonly reported simulator sickness symptom in past research as well (e.g., Gower & Fowlkes, 1989). Comments from survey participants primarily indicated that the AGSS visual system was the main cause for the reported eye strain and discomfort. Some of the comments included: "seemed to be mostly due to poor helmet resolution and a mismatch between the two separate tubes [CRTs];" "seemed to be due to monocle adjustment and small area of visual acuity;" and "just a general hard time focusing on things in the box, trying to accommodate for lack of visual resolution." More research is recommended to determine which conditions (e.g., with or without motion) or tasks (e.g., scanning) are the most likely candidates to invoke simulator sickness symptoms in AGSS trainees, and what can be done to alleviate or minimize their occurrence.

Training Capability

Finally, we asked participants to rate from 1 (poor) to 5 (exceptional) the training capability of the AGSS on 39 required AG/S skills. For this assessment, we covered a broad array of skills, including ones the AGSS was not explicitly built to help train. Specifically, we wanted to assess: (a) whether the device was considered capable of training the skills it was built to help train (e.g., target acquisition); (b) whether there were skills that the AGSS was not explicitly designed to train (e.g., gun malfunctions) that were considered "trainable" in the AGSS; and (c) to what extent these skills were trainable in the AGSS. In order to extract this information, it was important to maintain the integrity of the entire scale in our analysis, rather than collapsing the scale into three levels as was done throughout the Kolmogorov-Smirnov analyses. In addition, we probed participants for training capability ratings for both day and NVG night conditions. Their ratings did not differ between day and NVG and are, therefore, treated as overall ratings of training capability for each skill.

Table 13 lists the AG/S skills assessed in rank order of their mean rating of AGSS training capability. Their associated standard deviations are presented in the third column. This rank ordering simply illustrates which skills participants feel the AGSS is best suited to train. Although rank ordering alone is informative, we thought it would be worthwhile to group these skills into categories using cluster analysis, as previously described.

Table 13. Mean Ratings (Descending Order) and Standard Deviations of AGSS Training Capability for 39 AG/S Skills.

Gunner/Scanner Skill	Mean Rating	Standard Deviation
Voice Procedures	4.36	.67
Left, Right, Tail Call Responsibilities	4.18	.60
Left, Right, Tail Interactions	4.09	.54
Taxi and Hover Calls	4.00	.63
Crew Coordination/Overall	4.00	.63

Table 13. Concluded.

Threat Breaks	3.91	.83
Scanning	3.91	.94
Tactical Knowledge	3.82	.87
Radar	3.82	.98
Go-Arounds	3.82	.87
AAA	3.82	.98
Rules of Engagement	3.82	.87
Defensive Countermeasures	3.80	.63
Approaches and Landings	3.73	1.01
Gunner Cockpit Exchanges	3.73	1.10
Ammo Conservation	3.73	1.19
Tactical Approaches	3.64	1.03
Terrain Masking	3.55	.69
Safety and Judgment	3.45	.95
Terrain Obstacle Avoidance	3.45	.82
Search Operations	3.36	1.21
Communication System	3.36	1.03
Aircrew Briefing	3.36	1.36
Remote Operations	3.27	1.19
Tactical Mission Navigation	3.18	1.38
Radio Discipline	3.09	1.38
Use Limitations	3.09	1.45
Waypoint Identification	3.09	1.04
Target Acquisition	2.91	1.04
Knowledge of Directives	2.64	.81
Passenger Brief	2.18	1.54
Resource Management	1.91	.70
Checklist Procedures	1.55	.69
NVG Use and Limitations	1.20	.63
Light Signals	1.18	.40
Emergency Procedures	1.18	.40
Gun Malfunctions	1.09	.30
NVG Failure	1.00	.00
Aircraft Taping and Lighting	1.00	.00

When using cluster analysis there is often no single solution. Rather it is driven by experimenter interpretation as to where the optimal solution is in terms of the objects clustered. Figure 11, although still having 17 distinct clusters, was selected (forming at the 17th step) as the best grouping of the skills rated. We chose this step primarily because of the four large clusters that formed (although some of the two-skill clusters are also informative). These four large clusters separate the skills into distinct AG/S skill areas. The first cluster is crew coordination skills. The second is terminal area operation skills. The third is tactical skills. And, the fourth is "skills the AGSS was **not** designed to train" (requiring actual guns or NVGs to train). This is not meant to imply that the AGSS was designed and built to train the remaining 32 skills, however this category reflects the skills that the AGSS was never meant to train.

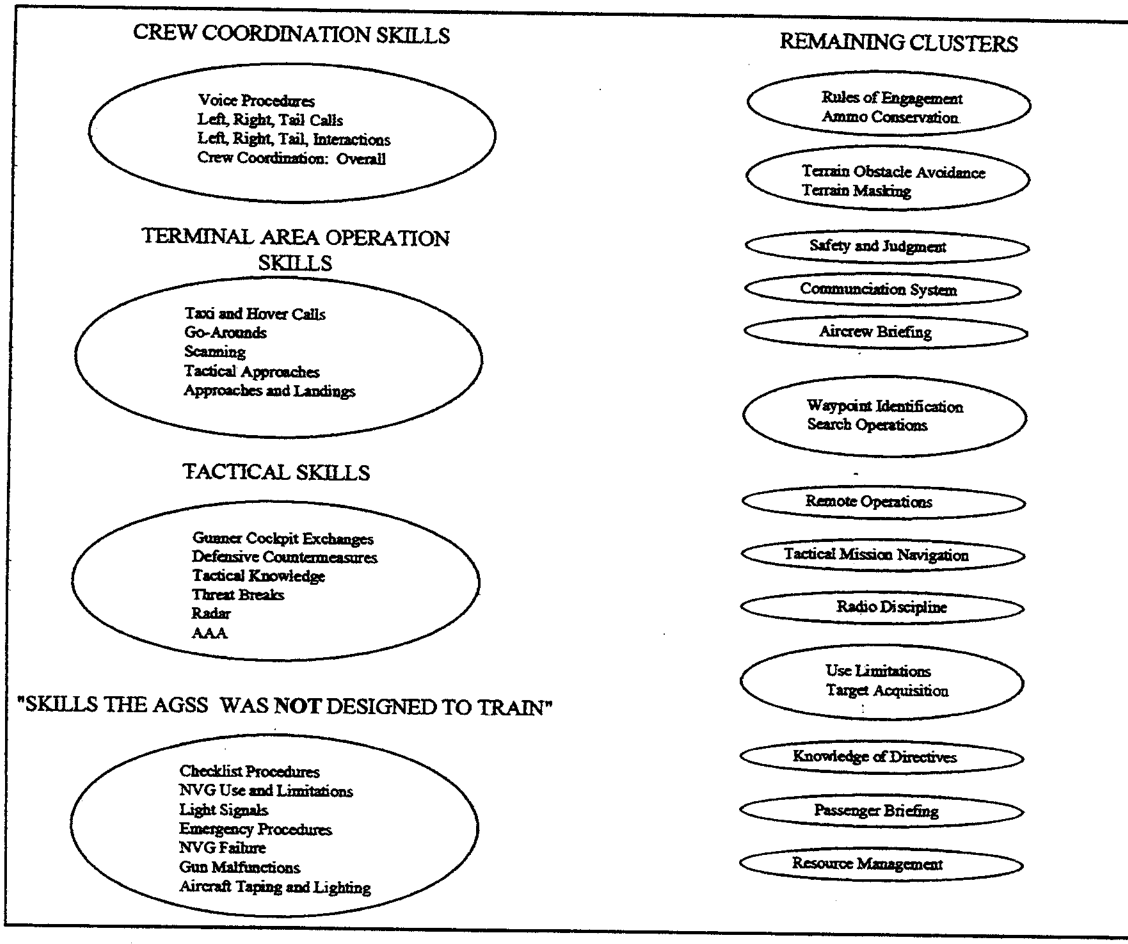

Figure 11. Cluster Analysis Output of 39 AG/S Skills.

Several interesting points arise from the rank orderings, standard deviations, and cluster analysis combined. First, and perhaps most important, there was considerable agreement among the raters (as evident by the small standard deviations listed in Table 13) concerning both the highly trainable (first three large clusters) and totally untrainable skills (last large cluster) in the AGSS. For the middle-range skill ratings (3s), there was more variability. Some of the comments associated with these skills suggested uncertainty, not based on the device, but because participants had not used the device in this capacity before. Other comments suggested that some training in these skill areas was possible with a little instructor imagination, but that it would not be as complete as in the aircraft. Combined, these factors led us to believe that there may be considerable untapped training potential of the AGSS across these middle-range skill areas. Table 13 also highlights one notable discrepancy between one of the key skills the AGSS was explicitly built to train, target acquisition, and its low mean training capability rating by participants. Three specific reasons were cited for participants' low ratings: poor visuals, inability to judge distances, and inaccurate modeling of the bullet path.

SUMMARY OF RESULTS AND RECOMMENDATIONS

All participants in the survey were quite positive about the training potential of the AGSS. Indeed, the most frequent positive comment across the board, even with the number of participant criticisms, was that the device provided unique training capabilities unavailable prior to the introduction of the AGSS into the 58 TRSS. With this said, participants' ratings and comments were extremely insightful as to improvements that could make the device an outstanding training medium for AG and FE training curricula. To summarize, the central findings, both positive and negative, associated with each section of the survey are presented in Table 14.

Table 14. Main Findings from Each Section of the Survey: Problems and Positives.

Survey Section	Main Problems Reported	Positive Aspects Noted
Helmet	⇒ CRT failure rate and discrepancies ⇒ Head-tracker: slow update rate ⇒ Alignment and fitting problems ⇒ Pads: type and method of attachment to helmet ⇒ Cords: too short for requirements of tail position and they sometimes get caught during training	⇒ Lightweight, less than those used in the aircraft
Trainee Stations	⇒ Virtual mapping of stations and guns, a few noted problems	⇒ Mapping of outside of ownship
IOS	⇒ Second instructor position lacks the ability to talk directly with students in the AGSS ⇒ Space ball: poor modeling of ownship aerodynamics, very difficult to use ⇒ Task saturation: monitoring students, running IOS, flying moving models, loading threats, etc. becomes quickly overwhelming ⇒ Layout of screens potentially a contributor to task saturation and instructor inefficiency	⇒ Threats on ground track map page ⇒ Similarities with other 58 TRSS IOSs makes it easy to learn
Weapons Simulation	⇒ Poor modeling of bullet path, no lead and lag ⇒ Insufficient number of tracers viewed per rounds fired	⇒ General capability never before available ⇒ Feedback on gunner performance
Visuals	⇒ Alignment procedures ⇒ Alignment of virtual and physical environment ⇒ Poor color quality ⇒ Visual continuity (slow update rate) ⇒ Limited FOV for daytime operations	⇒ Explosions, including secondaries
Physiological Symptoms	⇒ 50% of participants noted the occurrence of simulator sickness symptoms during and after AGSS training ⇒ Eye strain and visual discomfort were reported by a significant proportion of survey participants	⇒ Reported symptoms did not disrupt training
Training Capability	⇒ Visuals make it difficult to train certain tasks	⇒ Outstanding tool for training voice procedures, terminology, and crew coordination ⇒ Rated training capability will be higher when the AGSS is integrated

Additionally, throughout this report, we have made recommendations for improving those AGSS components that trainees rated unfavorably and which were frequently criticized. In Table 15, we summarize the main problem areas and our recommendations for their improvement. The table provides gross estimates of the cost and training "payoff" associated with each recommendation.

Table 15. Main AGSS Problem Areas, Recommendations for Improvement, Associated Cost Estimates, and Potential Training Payoff Estimates.

Problem Area	Recommendation	Cost	Training Payoff
CRT Failure Rate	⇒ Invest in higher quality CRTs.	HIGH	HIGH
CRT Discrepancies	⇒ Purchase new CRTs more frequently.	MEDIUM	HIGH
Slow Head-tracker Update Rate	⇒ Invest in higher quality, more recent technology.	HIGH	MEDIUM
	⇒ Introduce slower NVG scanning rates early on in AGSS training.	NONE	HIGH
Poor Helmet Alignment and Fitting Procedures	⇒ Have more training and standardization of procedures.	LOW	HIGH
Poor Pads	⇒ Invest in higher quality pads.	LOW	HIGH
Length of Electronic and Communication Cables	⇒ Invest in longer cables.	MEDIUM	MEDIUM
	⇒ Provide a means of tethering cables off the students' shoulders.	LOW	MEDIUM
Virtual Mapping of Stations (re: other players in other positions)	⇒ Map players in all positions.	LOW*	LOW
	⇒ Do not map any players in other positions.	LOW	LOW
Second Instructor Position's Lack of Communication Capability	⇒ Provide capability to communicate directly with students in the AGSS.	MEDIUM	VERY HIGH
Problems with Space Ball for Ownship Flying	⇒ Change software modeling of aerodynamics.	HIGH	MEDIUM
	⇒ Change controls to a joystick.	HIGH	HIGH
	⇒ Do not use space ball for ownship flying.	NONE	LOW
High Levels of Instructor Reported Task Saturation at IOS	⇒ Operate only in integrated mode.	HIGH	MEDIUM
	⇒ Limit number of students in AGSS.	MEDIUM	VERY LOW
	⇒ Provide two instructors for training.	MEDIUM	HIGH
	⇒ Change layout of instructor screens.	MEDIUM	HIGH

Table 15. Concluded.

Problem Area	Recommendation	Cost	Training Payoff
Poor Modeling of Bullet's Path	⇒ Change modeling.	HIGH	VERY HIGH
	⇒ Provide training on aircraft versus AGSS discrepancies.	LOW	MEDIUM
Low Number of Tracers Visible Per Rounds Fired	⇒ Increase number of tracers per rounds fired.	LOW*	MEDIUM
	⇒ Provide training on aircraft versus AGSS discrepancies and reasons.	LOW	MEDIUM
Alignment and Modeling of Virtual Environment (e.g., gun on pivot point)	⇒ Improve modeling.	LOW	HIGH
Poor Object and Visual Scene Detail	⇒ Improve modeling and texturing of data base and moving models.	MEDIUM	HIGH
Poor Color Quality	⇒ Improve colors.	LOW	HIGH
Reduced FOV for Daytime Operations	⇒ Change size of windows to accommodate VR helmet.	MEDIUM	MEDIUM
Poor Visual Quality	⇒ Improve visual systems.	HIGH	VERY HIGH
	⇒ Improve other systems (e.g., CRTs)	HIGH	HIGH

*NOTE. Associated costs may be low, but due to current limitations in the IG, these suggestions may not be possible.

The shaded rows in the table indicate areas in which improvements have already been made to the AGSS since the completion of the survey. Alignment procedures and fitting procedures have been greatly improved, and the current level of expertise is high among the Lockheed Martin personnel maintaining and working with the AGSS. However, the means of transferring this knowledge is still largely through demonstration and trial and error. This suggests a need to impose greater documentation and dissemination of this process, such as by writing out step-by-step instructions for distribution to all AG/S trainers. The modeling of the gun and its pivot point has also been improved dramatically since the survey, and observed responses have been overwhelmingly positive in terms of greater student acceptance of the device. In addition, the visual system and various aspects of the data bases used in the AGSS are in constant flux. As a consequence, several visual features of the AGSS have also been improved since the survey. In particular, the colors and the detail and texturing of many of the moving models have been modified. These improvements have all been well received by AGSS students and instructors.

As for the non-shaded items in Table 10, we have attempted to include recommendations that have potentially significant training payoffs. The cost is based on the estimated dollar costs for providing the hardware or software modifications, the costs of extra training time and/or

scheduling of additional personnel (e.g., operating in the integrated mode or using an additional AGSS instructor).

FUTURE RESEARCH

The next step in the human factors analysis of the AGSS is twofold: (1) user acceptance and (2) training effectiveness (remember Figure 2). Both of these areas have begun to be explored by the Kirtland AFB research team. In terms of user acceptance, the 58 TRSS has created a series of questionnaires for instructors and students to determine their responses to the device immediately following training sessions. The questions cover a wide array of topics including, human factors aspects of the device, training provided, and device fidelity.

In regard to training effectiveness, we are looking at device impact on skill acquisition and performance (largely guided by the skill ratings acquired from this survey, see Table 12) and AG/S training hours in the aircraft. Without going into too much detail, we are: (a) observing training for five scheduled Mission Qualification AGSS missions, (b) attaining skill ratings of trainees by instructors for these missions, (c) obtaining objective performance pages when possible for these missions, (d) securing ratings of skill performance from the flight line on students receiving AGSS training, and (e) analyzing AG/S training folder data. It is through these primary means that we hope to determine the impact of the AGSS to the AG training system.

Finally, because these various mechanisms are in place, we can also address the training effects of system upgrades potentially resulting from this survey. For example, the AGSS has currently been used solely as a stand-alone trainer because of delays in the integration process. We will have several months of data on a significant number of students who received only AGSS stand-alone training. As soon as the device becomes integrated, we will be able to compare those students skills and device opinions to those who start to receive both stand-alone and integrated AGSS training.

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HELMET - Did you experience any breakage, malfunction, or usability problems in the following?		**EQUIPMENT** - Did you experience any of the following equipment problems?	
N - Never **R - Rarely** **S - Sometimes** **O - Often** **A - Always**			
1. Visor?	N R S O A	1. Poor helmet fit?	N R S O A
2. Eye Piece?	N R S O A	2. Eye-piece misalignment?	N R S O A
3. Head-tracker?	N R S O A	3. Slippage?	N R S O A
4. Comm. cable?	N R S O A	4. Neck fatigue?	N R S O A
5. Elect. cable?	N R S O A	5. Hot spots?	N R S O A
6. Other:	N R S O A	6. Chin straps chafing?	N R S O A
		7. Chin straps choking?	N R S O A
		8. Unbalanced weight?	N R S O A
		9. General discomfort?	N R S O A
		10. Other:	N R S O A

CABLES

1. Do the cables unduly tug at the back of your head?	Y	N
2. Do the cables limit the amount of **normal movement** around the aircraft?	Y	N
3. Do the cables hinder **normal head movements** (e.g., scanning ability)?	Y	N
4. Do the cables interfere with task performance (e.g., target acquisition)?	Y	N
5. If YES, indicate which tasks:		

HELMET ADJUSTMENTS

1. How long did it take to put on and adjust the helmet the first time?		
2. How long did it usually take to put on and adjust the helmet?		
3. Once the helmet was adjusted, did you require readjustments during the training time?	Y	N

AGSS TRAINEE STATIONS

1 - Poor **2 - Min. Req.** **3 - Standard** **4 - Outstanding** **5 - Exceptional**				
TRAINEE STATION	Rating	**WEAPONS SIMULATION**	MiniGun	.50 Cal
1. Overall station set-up?		1. Gun Recoil?		
2. Gun set-up?		2. Gun Sounds?		
3. Gun feel?		3. Gun Position?		
4. Virtual mapping - acft. envmt.?		4. Gun Weight/Feel?		
5. Virtual mapping - other stations?		5. Gun Controls?		
6. Mobility within station?		6. Airstream Effects?		
7. Crew seats and harnesses?		7. Tracer Fidelity?		
8. Other:		8. Ballistic Model?		
		9. Gun Alignment?		
		10. Target Acquisition?		
		11. Other:		

INSTRUCTOR OPERATING STATION - IOS

1. Does the noise level of the surrounding simulators affect your ability to train at the AGSS IOS?	Y	N
2. While at the IOS, does your inability to see the student in the AGSS affect your ability to instruct?	Y	N
3. Do you become fully task saturated at the AGSS IOS? With 1, 2, or 3 students? (Circle choice)	Y	N
4. Do the visual distractions in the simulator bay (e.g., the flashing red light of the MH-53J WST) affect your ability to train at the AGSS IOS?	Y	N

INSTRUCTOR OPERATING STATION - IOS (Continued)

1 - Poor 2 - Min. Req. 3 - Standard 4 - Outstanding 5 - Exceptional			
FEATURES	Rating?	INSTRUCTOR STATION PAGES	Rating
1. Instructor screens?		1. Ground track map pages?	
2. Information content?		2. Gunner performance monitoring?	
3. Instructor screens layout?		3. Threat status page?	
4. Student screens information content?		4. Flare monitoring page?	
5. Student screens layout?		5. Other:	
6. Station layout (position of screens)?			
7. Space ball?			
8. Other:		9. Overall IOS assessment?	

INSTRUCTOR & STUDENT INTERACTION and COMMUNICATION SYSTEM

1. Did you have any problems hearing/understanding the instructor while in the AGSS?	Y	N
2. Did you have any problems hearing/understanding students while at the AGSS IOS?	Y	N
3. Did you have any problems hearing or understanding other crewmembers?	Y	N
4. Was the instructor able to provide timely feedback while you were in the AGSS?	Y	N
5. Have you had any problems with communications in the helmet/device?	Y	N
6. Was the sound quality and background noise comparable to the aircraft?	Y	N
- If **YES**, from a training perspective, is this good?	Y	N
- If **NO**, from a training perspective, is this good?	Y	N

VISUAL SYSTEM

N - Never R - Rarely S - Sometimes O - Often A - Always		
	While Flying in AGSS?	After Flying in AGSS?
1. Visual Discomfort?	N R S O A	N R S O A
2. Headache?	N R S O A	N R S O A
3. Double Vision?	N R S O A	N R S O A
4. Blurred Vision?	N R S O A	N R S O A
5. Disorientation?	N R S O A	N R S O A
6. Eye Strain/Fatigue?	N R S O A	N R S O A
7. Neck Strain?	N R S O A	N R S O A
8. Stomach Discomfort?	N R S O A	N R S O A
9. Nausea?	N R S O A	N R S O A

VISUAL SYSTEM - DAY and NIGHT OPERATIONS

1 - Poor 2 - Min. Req. 3 - Standard 4 - Outstanding 5 - Exceptional			
FEATURE	Rating	Representation of Specific Objects	Rating
1. Visual resolution (object detail)?		1. 747 aircraft?	
2. Visual scene clarity?		2. Airborne helicopter?	
3. Visual scene completeness?		3. Jeeps?	
4. Visual scene continuity?		4. Trucks?	
5. Meaningful depth?		5. SAM sites?	
6. Image stability?		6. Trees?	
7. Image clarity?		7. Roads?	
8. Image alignment?		8. Runways?	
9. Image color?		9. Explosions?	
10. Visual system brightness?		10. Other?	
11. Visual system contrast?			
12. Object detectability?			
13. Distance Perception?			
14. Other?			
15. Overall Visual System assessment?			

VISUAL SYSTEM - Field-of-View

1. Did you achieve a full FOV?	Y	N
- If **NO** what items were you unable to see? (List here)		
2. Did your FOV change when you moved your head Vertically?	Y	N
3. Did your FOV change when you moved your head Horizontally?	Y	N
4. Did your FOV change when you moved your head Forward?	Y	N
5. Did your FOV change when you moved your head Backward?	Y	N
6. Were you able to execute a normal scan?	Y	N

DEVICE CAPABILITY FOR TRAINING CERTAIN SKILLS

1 - Poor 2 - Min. Req. 3 - Standard 4 - Outstanding 5 - Exceptional					
SKILL	Rating		SKILL	Rating	
	Day	Night		Day	Night
1. Voice Procedures?			22. Tactical knowledge?		
2. Checklist Procedures?			23. Rules of Engagement?		
			24. Terrain/Obstacle avoid.?		
3. Gunner Cockpit Exchanges?			25. Waypoint identification?		
4. Left/Right/Tail call resp.?					
5. Left/Right/Tail interactions?			26. Light signals?		
6. Radio Discipline?			27. Target acquisition?		
7. Aircrew briefing?			28. Ammo conserve?		
8. Passenger briefing?			29. Use limitations?		
9. Other:			30. Emergency procedures?		
10. Crew Coordination?			31. Gun malfunctions?		
			32. NVG failure?		
11. Safety and judgment?			33. Aircraft taping and lighting?		
12. Resource management?			34. NVG use and limitations?		
13. Knowledge of directives?			35. Radar?	XX	
14. Communication system?			36. AAA Threats?	XX	
15. Taxi and hover calls?			37. Terrain masking?		
16. Approaches and landings?			38. Threat breaks?	XX	
17. Go-arounds?			39. Countermeasures?		
18. Scanning?			40. Overall Training Capability?		
19. Search operations?					
20. Remote operations?					
21. Tactical approaches?					

MISCELLANEOUS

1. Did the AGSS fly like the aircraft?	Y	N
2. Did you ever feel disoriented in the AGSS?	Y	N
If **YES**, under what circumstance(s)?		
a. During Target Acquisition?	Y	N
b. During TF/TA?	Y	N
c. During Takeoff?	Y	N
d. During Landings?	Y	N
e. During Crashes?	Y	N
f. During System Reset?	Y	N
g. When Instructor is flying with the space ball?	Y	N
h. When flying in Left Station?	Y	N
i. When flying in Right Station?	Y	N
j. When flying in Tail Station?	Y	N
3. If you ever felt disoriented, did a particular system contribute to this perception?	Y	N
4. Were you satisfied with the motion system?	Y	N

APPENDIX B

Participant Ratings: Raw Data

Component	Rating, frequency					
HELMET	**1**	**2**	**3**	**4**	**5**	**N**
Visor	0	0	2	0	9	11
Eye Piece Combiner	0	1	2	2	6	11
Chinstrap	11	0	0	0	0	11
Head-tracker	0	0	5	3	3	11
Communication Cable	0	1	2	1	7	11
Electronics Cable	0	0	3	1	7	11
CRTs	0	2	3	1	5	11
Helmet Fit	1	0	3	4	3	11
Eye Piece Misalignment	0	0	0	3	8	11
Slippage	0	0	3	4	4	11
Neck Fatigue	0	0	1	0	10	11
Hot Spots	1	1	2	3	4	11
Chin Strap Chafing	0	2	0	1	8	11
Chin Strap Choking	0	0	1	0	10	11
Unbalanced Weight Dist.	0	1	0	1	9	11
General Comfort	0	1	2	5	3	11
Helmet Pads	1	1	0	5	4	11
TRAINEE STATIONS	**1**	**2**	**3**	**4**	**5**	**N**
Gun Set Up	0	1	6	2	2	11
Gun Feel	0	0	0	6	5	11
VR Aircraft Interior	0	3	1	4	3	11
VR Other Stations	0	1	5	3	2	11
Mobility within Station	0	1	5	3	2	11
Crew Seats	0	1	2	1	0	4
Crew Harnesses	1	0	3	0	1	5
Overall Rating	0	1	3	4	3	11
IOS	**1**	**2**	**3**	**4**	**5**	**N**
Instructor Screen Content	0	1	2	5	0	8
Instructor Screen Layout	0	0	2	5	1	8
Student Screen Content	0	1	2	4	1	8
Student Screen Layout	0	1	3	4	0	8
Station Layout	0	0	3	5	0	8
Space Ball - Models	2	0	1	5	0	8
Space Ball - Ownship	5	3	1	0	0	9
Second Instructor Position	1	3	2	1	0	7
Ground Track Map Page	0	0	5	3	0	8
Gunner Performance Page	0	0	2	5	1	8
Crew Performance Page	0	0	1	7	0	8
Threat Status Page	0	0	4	2	1	7
Flare Monitoring Page	0	0	5	2	0	7
Overall Rating	0	0	2	5	1	8

Participant Ratings: Raw Data

Component	**Rating, frequency**					
WEAPONS SIMULATION	1	2	3	4	5	N
Gun Recoil	0	0	4	5	1	10
Gun Sounds	0	0	5	5	1	11
53 Gun Position	0	2	2	4	2	10
60 Gun Position	0	0	2	1	1	4
Gun Weight and Feel	0	1	3	4	3	11
Gun Controls	0	0	1	5	5	11
Airstream Effects	0	2	2	5	2	11
Tracers	1	4	3	2	1	11
Ballistic Model	0	1	5	2	3	11
Gun Alignment	2	2	5	2	0	11
Gun Pivot Point	2	2	4	2	1	11
Target Acquisition	0	5	2	2	2	11
Overall Rating	0	0	7	1	3	11
VISUAL SYSTEM	1	2	3	4	5	N
Visual Resolution: Object Det.	0	5	3	1	2	11
747	0	0	5	3	1	9
Hind-D	0	4	1	3	2	10
Jeep	1	3	2	3	1	10
Truck	0	4	2	3	0	9
SAMs	0	3	3	2	1	9
Trees	1	4	4	2	0	11
Roads	0	2	6	2	1	11
Runways	0	2	2	4	2	10
Explosions	0	1	1	8	1	11
Field of View	0	0	6	4	1	11
Brightness	0	0	5	5	1	11
Contrast	0	3	4	3	1	11
Visual Resolution: Scene Det.	0	1	5	4	1	11
Object Detectability	2	5	1	3	0	11
Distance Perception	2	2	2	4	1	11
Scene Clarity	0	3	4	4	0	11
Scene Completeness	0	1	5	5	0	11
Scene Continuity	0	2	5	2	2	11
Scene Depth	1	2	2	5	1	11
Image Stability	0	1	3	5	2	11
Image Clarity	0	4	1	5	1	11
Alignment	0	2	4	5	0	11
Image Color.	0	2	4	5	0	11
Overall Rating	0	1	6	4	0	11

Participant Ratings: Raw Data

Component	Rating, frequency					
TRAINING CAPABILITY	1	2	3	4	5	N
Voice Procedures	0	0	1	5	5	11
Checklist Procedures	6	4	1	0	0	11
Gunner-Cockpit Exchanges	1	0	2	6	2	11
Left, Right, Tail Call Resp.	0	0	1	7	3	11
Left, Right, Tail Interactions	0	0	1	8	2	11
Radio Discipline	2	1	4	2	2	11
Aircrew Briefings	1	3	0	5	2	11
Passenger Briefings	5	3	1	0	2	11
Crew Coordination Overall	0	0	2	7	2	11
Safety and Judgment	0	2	4	4	1	11
Resource Management	3	6	2	0	0	11
Knowledge of Directives	1	3	6	1	0	11
Communication Systems	0	2	5	2	2	11
Taxi/Hover Clearance Calls	0	0	2	7	2	11
Approach/Landing Calls	0	2	1	6	2	11
Go-Arounds	0	1	2	6	2	11
Scanning	0	1	2	5	3	11
Search Operations	1	1	4	3	2	11
Remote Operations	1	2	4	3	1	11
Tactical Approaches	0	2	2	5	2	11
Tactical Knowledge	0	1	2	6	2	11
Radar/IR	0	1	3	4	3	11
AAA	0	1	3	5	2	11
Terrain Masking	0	0	6	4	1	11
Threat Breaks/Evas. Maneuvers	0	1	1	7	2	11
Countermeasures	0	0	3	6	1	10
Rules of Engagement	0	1	2	6	2	11
Tactical Navigation	2	1	2	5	1	11
Terrain/Obstacle Avoidance	0	1	5	3	2	11
Waypoint Identification	1	1	6	2	1	11
Light Signals	9	2	0	0	0	11
Emergency Procedures	8	3	0	0	0	11
Target Acquisition	1	3	3	4	0	11
Ammo Conservation	1	0	3	4	3	11
Use Limitations	2	2	1	3	3	11
Gun Malfunctions	10	1	0	0	0	11
NVG Failure	10	0	0	0	0	10
Aircraft Taping and Lighting	10	0	0	0	0	10
NVG Use and Limitations	9	1	0	0	0	10